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A Review of the Recent Scientific Literature on Irrigation Induced and Enhanced Wetlands

by Jacob F. Berkowitz and Darrell E. Evans

PURPOSE: The following report provides a preliminary review of the recent scientific literature pertaining to the ecology and management of irrigation induced and enhanced wetlands. The report is designed to provide insight into the complexity of identifying irrigated wetlands for jurisdictional purposes, outline the current state-of-the-science regarding irrigated wetlands, and provide basic guidance on future actions required to address issues related to irrigated wetlands.

OUTLINE: The report contains: 1) a brief introduction, 2) background information summarizing the major issues associated with irrigated wetlands, 3) a description of the methods utilized in drafting the literature review, 4) summary of findings regarding the major categories of available scientific literature, and 5) appendices containing over 80 references, associated abstracts, and sources of additional information.

INTRODUCTION: The U.S. Army Corps of Engineers (USACE) is responsible for administering provisions Section 404 of the Clean Water Act, including the permitting and regulation of wetlands and other aquatic resources. Wetlands are identified based upon the observation of indicators of wetland hydrology, hydrophytic vegetation, and hydric soils (Environmental Laboratory 1987; USACE 2008). In areas exposed to extended periods of irrigation, wetland indicators may be supported solely or in part by presence of irrigation waters (USACE 2010). The presence of irrigation activities has resulted in complex and difficult wetland delineations, especially in the arid west region (Department of Ecology 2010). In order to address the challenges associated with identifying wetlands in irrigated areas, ERDC staff developed a multi-year proposal designed to provide technical support regarding irrigated wetlands issues. The following literature review represents the first phase of this effort.

BACKGROUND: Agricultural activities throughout the United States resulted in the loss of wetland areas, including a 90% reduction in historical wetlands of California's central valley (Lemly et al. 2000; Garone 2011) and a steady decrease in aquifer levels capable of supporting natural wetlands (Heermann 2003). However, irrigation activities associated with agriculture create and support irrigated wetlands due to the addition of irrigation waters and seasonal increases in stream levels as a result of upstream irrigation (Ekstein and Hygnstrom 1996; Sueltenfuss et al. 2013; Kendy and Bredehoeft 2006; Strange et al. 1999). Gollehan and Quimby (2000) reported that over 17 million ha of irrigated land occur in the western United States and many irrigation activities have persisted in the region for over 125 years (USACE 2010). Following extended periods of irrigation, all three factors used for wetland identification (i.e., hydrology, vegetation, and soils) can exhibit alteration (Environmental Laboratory 1987; USACE 2008; Summerford 2009).

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Irrigated wetlands form adjacent to irrigated agricultural lands and are commonly located: 1) along the perimeter of large scale agricultural operations, 2) in close proximity to irrigation ditches and canals transporting water for agricultural use, and 3) in areas subject to flood irrigation (e.g., ricefields) (Peck and Lovvorn 2001). In some cases, irrigation waters provide the sole source of wetland hydrology and the wetlands cease to exist (i.e., “dry-up”) in the absence of ongoing agricultural manipulation (Department of Ecology 2010). These wetlands are referred to as irrigation induced wetlands (Adamus 1993). In many cases, irrigation water provides additional hydrologic support and expands the boundaries of existing wetland areas (Crifasi 2005). These areas are defined as enhanced wetlands (Adamus 1993). Additionally large-scale land alterations (e.g., laser-leveling, canal construction) demonstrate the potential for the creation of induced wetlands that would endure in the absence of irrigation due to the permanence of anthropogenic changes in the landscape and hydrology.

Irrigated wetlands create unique regulatory challenges because they display many of the characteristics of natural wetlands and in many cases it remains unclear if the wetland would persist, decrease in size, or disappear following the removal of irrigation waters (Curry 1992; Harvey and Sibrey 2001). Jurisdictional wetland delineations/determinations in irrigation induced wetlands can be complicated. Notably, soils in irrigated wetlands may or may not exhibit hydric characteristics depending on the natural hydrologic regime, parent material, irrigation frequency, method, duration, and other factors. For example, the development of hydric soils requires considerable periods of inundation, flooding, or ponding (Richardson and Vepraskas 2001). As a result, hydric soil indicators may not become apparent for several years following the application of irrigation waters (Tiner 1999). Hydric soil morphologies also persist for years following decreases in wetland hydrology. In addition to soil alterations, irrigated areas exhibit managed plant communities (e.g., irrigated pastureland, planted row crops, or rice fields), making determinations of hydrophytic vegetation difficult or irrelevant. The response of natural hydrophytic vegetation to irrigation inputs further complicates the delineation of wetland plant communities (USACE 2008).

As a result of this irrigation induced alteration to indicators of hydric soils and hydrophytic vegetation, regulators charged with making wetland determinations in areas exposed to irrigation activities focus on the presence or absence of indicators of wetland hydrology when irrigation activities have temporarily been discontinued (USACE 2012). Examining potential wetland areas for indicators of wetland hydrology during the typical wet portion of the year (i.e., the early portion of the growing season) during a normal climatic period provides one practical method for identifying wetlands that would persist in the absence of irrigation activities (USACE 2010). If regulators determine that indicators of wetland hydrology, hydrophytic vegetation, and hydric soils are being maintained on the site solely as a result of irrigation, and that wetland conditions would cease to persist in the absence of irrigation inputs, regulatory jurisdiction is not afforded under section 404 of the Clean Water Act (Department of Ecology 2010; USACE 2012).

METHODS: Information contained in this review of the literature provides a source of state-of-the-science knowledge, helping define the challenges posed by irrigated wetland areas and aid in their management. Our synthesis of irrigation induced wetlands literature began with a review of 292 commercially available, on-line databases of technical articles, conference proceedings, white papers and university/extension service publications (e.g., theses, dissertations, and technical reports; Appendix A). Databases were searched for information relating to wetlands created or

altered during normal agricultural irrigation practices. Pertinent citations were imported into a bibliographic database (EndNote[®]) and categorized by subject.

The literature review produced over 1200 potential references relating to irrigation, hydrology, and vegetation, fauna, distribution, and regulation of irrigated agricultural wetlands. References were evaluated for applicability and categorized into 7 broad groups. Full text versions of reprints were obtained whenever possible.

SUMMARY OF FINDINGS: Over 80 pertinent documents relating to irrigated wetlands are included in the current literature review. Citations were obtained from 70 peer reviewed technical journals (Appendix A), federal and state agency technical reports, conference proceedings, university theses, and other sources (Appendix B). All materials underwent categorization into 7 broad categories including: 1) irrigated wetland distribution and geographic range, 2) regulatory status, 3) irrigated wetland creation in agricultural landscapes, 4) wildlife habitat, threatened and endangered species, 5) water quality, 6) irrigated wetland hydrology and soils, and 7) irrigated wetland vegetation. A brief summary detailing the major themes observed within each category is presented below.

1) Distribution/Geographic Range

No single document effectively summarizes the distribution and extent of irrigated wetlands throughout the nation. Gollehon and Quimby (2000) provide an analysis of the extent of irrigation across the western regions of the US, while Kath et al. (2010) provides data on 251 wetlands occurring in 3 regions. Garone (2011) discusses irrigated wetland distributions (historic and contemporary) within the central valley of California. Additionally, Tiner (1999) and others discuss irrigated wetlands associated with rice fields in Louisiana and other locations, and Lemly et al. (2000) presents data on agricultural impacts to wetlands in Nevada, California, and several international areas. However, the available literature fails to identify any comprehensive analysis of distribution, condition, or extent of irrigated wetlands within the United States.

2) Regulatory Status

The application of irrigation waters poses challenges to wetland delineation and jurisdictional determinations in irrigated wetlands (USACE 2012; Department of Ecology 2010). Agricultural activities involving irrigation display the potential to: a) create wetlands in upland areas, b) enhance and expand wetlands located in natural wetland areas, c) alter wetland types and functions, and d) alter groundwater and surface water dynamics affecting wetland areas (USACE 1987; 2008; Kath et al. 2010). The application of irrigation waters can result in changes to all three factors utilized by wetland delineators (USACE 2010) including indicators of hydrophytic vegetation, wetland hydrology, and hydric soils. Department of Ecology (2010) introduces many of the elements associated with the identification and management of irrigated wetlands. Additionally, USACE (2012) provides a description of the issues and regulations associated with irrigated wetlands. The document also provides guidance and approaches for making wetland delineation determinations in irrigated wetlands. The alterations to hydric soil and hydrophytic vegetation indicators observed in irrigated wetlands require

wetland delineations to rely on indicators of wetland hydrology that occur following cessation of irrigation activities.

3) Wetland Creation in Agricultural Landscapes

A number of resources discuss both intentional and unintended creation of wetlands via application of irrigation waters. For example, Ekstein and Hygnstrom (1996) describe the unintentional increase in the number of wetlands associated with irrigation and increased regional water tables in central Nebraska. Crifasi (2005), Hibbs et al. (2011), Moreno-Mateos et al. (2009) and others also describe unintentional wetland creation in Colorado, California, and Europe. Sueltenfuss (2012) and Sueltenfuss et al. (2013) discuss the causes, extent, identification, and measurement of irrigated wetlands created in Colorado. Conversely, Call (2001) and Bergquist et al. (2011) discuss the intentional creation of wetlands in irrigated areas in order to increase wetland functionality, improve water quality, and provide wildlife habitat. Although no single document provides a comprehensive synopsis of irrigated wetlands, Adamus (1993) addresses irrigated wetlands located throughout the Colorado Plateau region; his analysis includes information on faunal habitat as well as an ecological assessment approach for irrigated wetland in that region.

4) Wildlife Habitat, Threatened and Endangered Species

Reference materials associated with faunal habitat (especially waterfowl) make up the vast majority of available literature resources in irrigated wetlands (Remsen et al. 1991; White and Main 2005; Whiles and Golowitz 2001; Peralta and Walker 2004). For example, Taft and Elphick (2007a) provide a bibliography containing over 400 articles examining waterbird usage of agricultural lands. Further, Czech and Parsons (2002) provide an excellent review of agricultural wetlands and their importance to waterfowl. These authors as well as Taft and Elphick (2007b) emphasize that over 1.5 million km² (150 million ha) rice fields are found across the globe, and that these irrigated wetlands provide important foraging sites for a number of species. Smith and Shinn (1994), Garone (2011) and others examine wetland associated with the central valley of California. Several authors suggest that irrigated wetlands provide foraging habitat values equivalent to natural wetlands (Elphick 2000). However, Fasola and Ruiz (1996) and others identify potential drawbacks to the use of irrigated wetlands by waterfowl including potential exposure to pesticides, rapid changes in landuse, and large scale hydrologic alteration.

In addition to habitat creation and maintenance, irrigated wetlands also support a variety of threatened and endangered species (Adamus 1993). For example, Bergquist et al. (2001) discusses implications of irrigated wetlands and mitigation to the giant garter snake (*Thamnophis gigas*) in California, Thrauth et al. (2006) addresses potential impacts to amphibians including the Illinois chorus frog (*Pseudacris streckeri illinoensis*) in Arkansas, and Gray et al. (2004) examines several amphibians including the barred tiger salamander (*Amoystoma tigrinum mavortium*) in Texas. Additionally, Peck et al. (2005) discusses irrigation activity impacts on threatened and endangered fish and avian species (e.g., cranes, terns, plovers, and sturgeon).

5) Water Quality

Many studies demonstrate the ability of natural and irrigated wetland ecosystems to improve water quality (Knox et al. 2008). However, a variety documents identify potential negative water quality impacts exacerbated by irrigation activities including salinization, eutrophication, and especially selenium contamination (Sieler 1997; Lemly 1994; Leighton and Wobeser 1994; Golterman 1995; Chow et al. 2004). Fennessey and Craft (2011) and Comin et al. (2001) provide examples of potential water quality improvements associated with removing agricultural areas from production and reestablishing un-manipulated wetlands. No single resource provides a comprehensive summary of the relationship between irrigated wetlands and water quality across the nation. However, the available literature does indicate that irrigation enhanced wetlands can play an important role in both water quality degradation (e.g., selenium contamination) and water quality improvement (e.g., nitrogen removal).

6) Irrigated Wetland Hydrology and Soils

Available literature provides insight into hydrologic changes induced by the withdrawal, application, and release of irrigation waters for agricultural activities (Fernald and Guldan 2006). Research studies provide tools and approaches for tracking irrigation waters through the landscape and predicting the effects of changes in irrigation regime on wetland areas. For example, Hibbs et al. (2011), Wurster et al. (2003), and Harvey and Sbiray (2001) utilize isotopic signatures in the investigation of wetland hydrology water sources. Other studies apply modeling approaches to determine the impact of surface and groundwater withdrawals on irrigated wetlands, stream base flow maintenance, and aquifer recharge (Farnald et al. 2010; De Voogt et al. 2000; Loaiciga 2007; Volseth et al. 2007). No single reference provides a comprehensive summary or guide to irrigated wetland hydrology, and many of the available studies focus on limited geographic areas and scales (Peck and Lovvorn 2001; Smith 2012; Strange et al. 1999). Several documents provide guidance on determining wetland hydrology in irrigated areas, with USACE (2010; 2012) identifying the need to examine agricultural areas during the wet portion of the year in the absence of irrigation additions.

7) Irrigated Wetland Vegetation

Few resources examine the impact of irrigation waters on wetland vegetation. Mushet (1992) examines growth patterns of four hydrophytic plant species in impounded wetlands located in California. Interestingly, Summerford (2009) investigates relationships between soil and vegetation characteristics in Wyoming to determine if a distinction could be made between naturally occurring and irrigation induced/created wetlands. Findings identified two factors, wetland index value and soil redox contrast, which displayed the ability to differentiate between natural wetlands and former upland areas.

CONCLUSIONS: The scientific literature provides significant resources regarding several aspects of irrigated agricultural wetlands, especially with regard to wildlife habitat and waterfowl usage. Additionally, a variety of tools (e.g., isotope tracking and numerical models) exist for conducting future investigations of irrigated wetlands. Unfortunately, most were conducted on an extremely limited spatial scale and do not have applicability over a larger geographic area. Few studies directly address questions of wetland jurisdiction in irrigated wetlands and the ability of

wetland conditions to persist in the absence of irrigation supplemented hydrology. Additionally, the impact of large scale land alterations associated with agricultural activities (including rice farming) remains unclear. In the absence of further investigations, existing guidance (e.g., USACE 2012; 2010; 2008) provides the most practical and defensible method for determining the regulatory status of irrigated areas.

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REFERENCES

- Abney, C. 2011. Designing Wetlands for Wildlife *Wetlands Engineering & River Restoration* 2001, 1-6.
- Adamus, P. R. 1993. Irrigated Wetlands Of The Colorado Plateau: Information Synthesis And Habitat Evaluation Method.
- An, S., H. Li, B. Guan., C. Zhou., Z. Wang., Z. Deng., Y. Zhi, Y. Liu, C. Xu, S. Fang, J. Jiang, and H. Li. 2007. China's Natural Wetlands: Past Problems, Current Status, and Future Challenges. *Ambio*, 36(4), 335-342.
- Bartzen, B. A., K. W. Dufour, R. G. Clark, and F. D. Caswell. 2010. Trends in agricultural impact and recovery of wetlands in prairie Canada. *Ecological Applications*, 20(2):525-538.
- Bergquist, R., J. Monk, D. Priske, and Y. Au Yeung. Stockton BNSF Intermodal Facility Wetland Mitigation *Wetlands Engineering & River Restoration* 2001.1-11.
- Call, J., C. 2001. Comparative Values of Wetlands Located near Salt Lake City, Utah. *Bridging the Gap*, 1-10.
- Champagne, P. 2007. Wetlands Natural Processes and Systems for Hazardous Waste Treatment. 189-256.
- Chow, A., K. Tanji, and S. Gao 2004. Modeling Drainwater Selenium Removal in Wetlands. *Journal of Irrigation and Drainage Engineering*, 130(1), 60-69.
- Comín, F. A., J. A. Romero, O. Hernández, and M. Menéndez, M. 2001. Restoration of Wetlands from Abandoned Rice Fields for Nutrient Removal, and Biological Community and Landscape Diversity. *Restoration Ecology*, 9(2):201-208.
- Conway, W. C., L.M. Smith, and J.D. Ray 2005. Shorebird Breeding Biology in Wetlands of the Playa Lakes, Texas, USA. *Waterbirds: The International Journal of Waterbird Biology*, 28(2):129-138.

- Crifasi, R. 2005. Reflections in a Stock Pond: Are Anthropogenically Derived Freshwater Ecosystems Natural, Artificial, or Something Else? *Environmental Management*, 36(5):625-639.
- Curry, R. R. 1992. WMRS Symposium Volume 4: The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. University of California, White Mountain Research Station
- Czech, H. A., and K.C. Parsons 2002. Agricultural Wetlands and Waterbirds: A Review. *Waterbirds: The International Journal of Waterbird Biology*, 25(ArticleType: research-article / Issue Title: Special Publication 2: Managing Wetlands for Waterbirds: Integrated Approaches / Full publication date: 2002 / Copyright © 2002 Waterbird Society), 56-65.
- Day, J. H. C. M. A. 1998. Water bird communities in rice fields subjected to different postharvest treatments. . *Colonial Waterbirds*, 21, 185-197.
- De Voogt, K., G. Kite, P. Droogers, and H Murray Rust. (2000). Modelling Water Allocation between a Wetland and Irrigated Agriculture in the Gediz Basin, Turkey. *International Journal of Water Resources Development*, 16(4):639-650.
- Department of Ecology. 2010. Focus on Irrigation-Influenced Wetlands. *State of Washington Department of Ecology*.
- Deppe, M., D.M. McKnight., and C. Blodau 2009. Effects of Short-Term Drying and Irrigation on Electron Flow in Mesocosms of a Northern Bog and an Alpine Fen. *Environmental Science & Technology*, 44(1):80-86.
- Ekstein, J. D., S. Hygnstrom. 1996. Fate of Wetlands Associated with the Central Nebraska Irrigation Canal System. *Great Plains Research*, 6:41-60.
- Elphick, C. S. 2000. Functional equivalency between rice fields and seminatural wetland habitats. *Conservation Biology*, 14(1), 181-191.
- Environmental Laboratory. 1987. Corps of Engineers Wetland Delineation Manual. *US Army Corps of Engineers. Wetland Research Program Technical Report Y-87-1*.
- Erwin, R. M., M. Coulter, and H. Cogswell. 1986. The Use of Natural vs. Man-Modified Wetlands by Shorebirds and Waterbirds. *Colonial Waterbirds*, 9(2), 137-138.
- Erwin, R. M. 2002. Integrated Management of Waterbirds: Beyond the Conventional. *Waterbirds: The International Journal of Waterbird Biology*, 25, 5-12.
- Fasola, M., and X. Ruiz. 1996. The Value of Rice Fields as Substitutes for Natural Wetlands for Waterbirds in the Mediterranean Region. *Colonial Waterbirds*, 19, 122-128.
- Fernald, A., S. Cevik., C. Ochoa, V. Tidwell, J. King, and S. Guldán. 2010. River Hydrograph Retransmission Functions of Irrigated Valley Surface Water–Groundwater Interactions. *Journal of Irrigation and Drainage Engineering*, 136(12):823-835.
- Fernald, A. G., and S.J. Guldán. 2006. Surface Water–Groundwater Interactions Between Irrigation Ditches, Alluvial Aquifers, and Streams. *Reviews in Fisheries Science*, 14(1-2):79-89.

- Fennessy, S., and C. Craft. 2011. Agricultural conservation practices increase wetland ecosystem services in the Glaciated Interior Plains. *Ecological Applications*, 21(sp1):S49-S64.
- Galbraith, H. A., Priyanie; A. Huber-Lee 2005. The effects of agricultural irrigation on wetland ecosystems in developing countries: a literature review *Comprehensive Assessment of Water Management in Agriculture Discussion Paper 1. International Water Management Institute (IWMI), Comprehensive Assessment Secretariat.*
- Garone, P. 2011. *The Fall and Rise of the Wetlands of California's Great Central Valley* (1 ed.).Berkeley, CA: University of California Press.
- Gollehon, N., and W. Quinby. 2000. Irrigation in the American West: Area, Water and Economic Activity. *International Journal of Water Resources Development*, 16(2), 187-195.
- Golterman, H. L. 1995. The labyrinth of nutrient cycles and buffers in wetlands: results based on research in the Camargue (southern France). *Hydrobiologia*, 315(1):39-58.
- Gray, M. J., L. M. Smith, and R. Brenes. 2004. Effects of Agricultural Cultivation on Demographics of Southern High Plains Amphibians. *Conservation Biology*, 18(5), 1368-1377.
- Harvey, F. E., and S. S. Sibray2001. Delineating ground water recharge from leaking irrigation canals using water chemistry and isotopes. *Ground Water*, 39(3):408-421.
- Heermann, D. F. (2003). A Reflection on Irrigation Changes *USDA-ARS-WMU*. Fort Collins, CO
- Hibbs, B.,M. Kelliher, and N. Erdelyi. 2011. Use of Environmental Isotopes to Determine Impacts on Wetlands Due to Lining of Irrigation Canals, Salton Sea Area, California *World Environmental and Water Resources Congress 2011*,1064-1074
- Huner, J. V., J.W. Clinton, and W. Norling. 2002. Managing Agricultural Wetlands for Waterbirds in the Coastal Regions of Louisiana, U.S.A. *Waterbirds: The International Journal of Waterbird Biology*, 25: 66-78.
- Kath, J., A. LeBrocq, C. Miller 2010. Wetland hydrology in an agricultural landscape: implications for biodiversity. *BALWOIS 2010: Water Observation and Information System for Decision Support, 25-29 May 2010, Ohrid, Macedonia.*
- Kendy, E., Y. Zhang, C. Liu, J. Wang, and T. Steenhuis. 2004. Groundwater recharge from irrigated cropland in the North China Plain: case study of Luancheng County, Hebei Province, 1949–2000. *Hydrological Processes*, 18(12):2289-2302.
- Kendy, E., and J. D. Bredehoeft. 2006. Transient effects of groundwater pumping and surface-water-irrigation returns on streamflow. *Water Resources Research*, 42(8), W08415.
- Khoa, S. N., K. Lorenzen.,C. Garaway,B. Chamsinhg, D. Siebert, and M. Randone. 2005. Impacts of Irrigation on Fisheries in Rain-Fed Rice-Farming Landscapes. *Journal of Applied Ecology*, 42(5), 892-900.
- Knox, A. K., R.A. Dahlgren, K.W. Tate, and E. R. Atwill. 2008. Efficacy of Natural Wetlands to Retain Nutrient, Sediment and Microbial Pollutants All rights reserved. *J. Environ. Qual.*, 37(5):1837-1846.

- Kushlan, J. A. 1986. The Management of Wetlands for Aquatic Birds. *Colonial Waterbirds*, 9(2), 246-248.
- Leighton, F. A., and G. Wobeser. 1994. Salinity and Selenium Content in Western Canadian Wetlands. *Wildlife Society Bulletin*, 22(1):111-116.
- Lemly, A. D. 1994. Irrigated agriculture and freshwater wetlands: A struggle for coexistence in the western United States. *Wetlands Ecology and Management*, 3(1):3-15.
- Lemly, A. D., R. T. Kingsford., and J. R. Thompson. 2000. Irrigated Agriculture and Wildlife Conservation: Conflict on a Global Scale. *Environmental Management*, 25(5):485-512.
- Loáiciga, H. 2007. Approach to Control the Depth of Water in Basin Irrigation and Wetland Flooding. *Journal of Irrigation and Drainage Engineering*, 133(5):500-504.
- Moreno-Mateos, D., C. Pedrocchi, and F. Comín 2009. Avian communities' preferences in recently created agricultural wetlands in irrigated landscapes of semi-arid areas. *Biodiversity and Conservation*, 18(4), 811-828.
- Mushet, D., N. Euliss, and S. Harris. 1992. Effects of irrigation on seed production and vegetative characteristics of four moist-soil plants on impounded wetlands in California. *Wetlands*, 12(3), 204-207.
- Peck, D., & Lovvorn, J. 2001. The importance of flood irrigation in water supply to wetlands in the Laramie Basin, Wyoming, USA. *Wetlands*, 21(3):370-378.
- Peck, D., D. McLeod, J. Hewlett, and J. Lovvorn 2004. Irrigation-Dependent Wetlands Versus Instream Flow Enhancement: Economics of Water Transfers from Agriculture to Wildlife Uses. *Environmental Management*, 34(6):842-855.
- Peralta, A., and W. Walker. 2004. Bird Use of Habitat Created by Irrigation and Drainage Practices in the Delta, Utah Area *Critical Transitions in Water and Environmental Resources Management*, 1-10.
- Remsen, J. V. S., M. M.; S. W. Cardiff; K. V. T. 1991. The importance of the rice growing areas of south-central Louisiana to winter populations of shorebirds, raptors, waders and other birds. . *Journal of Louisiana Ornithology*, 1:37-47.
- Seiler, R. L. 1997. Methods to Identify Areas Susceptible to Irrigation-Induced Selenium Contamination in the Western United States. *Fact Sheet FS-038-97*, U.S. Geological Survey (Department of the Interior).
- Smith, M. B. 2012. Quantifying the relationship between irrigation activities and wetlands in a northern Colorado watershed: assessing this added value of irrigation. MS thesis, Colorado State University.
- Smith, W. D., G. L. R., R. Shinn. 1994. A Guide to Wetland Habitat Management in the Central Valley. *California Department Fish and Game, California Waterfowl Association*.
- Strange, E. M., K. D. Faush, and A. P. Covich. 1999. Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. *Environmental Management*, 24(1):39-54.

- Sueltenfuss, J. 2012. The ecology of an irrigation system: wetland creation in an agricultural landscape MS thesis, Colorado State University.
- Sueltenfuss, J., D. Cooper, R. Knight, and R. Waskom. 2013. The Creation and Maintenance of Wetland Ecosystems from Irrigation Canal and Reservoir Seepage in a Semi-Arid Landscape. *Wetlands*, 33(5):799-810.
- Summerford, S. E. 2009. Characterization of soil/vegetation on flood irrigated hayfields in Grand Teton National Park, Wyoming : a predictive evaluation tool for agricultural wetlands. MS thesis, Montana State University.
- Taft, O. W., C. S. Elphick. 2007a. Waterbirds on Working Lands: Literature review and bibliography development. *National Audubon Society*, 44.
- Taft, O. W., C. S. Elphick. 2007b. Waterbirds on Working Lands: Chapter 3. Rice. *National Audubon Society*, 44.
- Tiner, R. W. 2002. Wetland indicators: A guide to wetland identification, delineation, classification, and mapping. CRC Press.
- Trauth, J. B., S.E. Trauth, and R.L. Johnson. 2006. Best Management Practices and Drought Combine to Silence the Illinois Chorus Frog in Arkansas. *Wildlife Society Bulletin*, 34(2), 514-518.
- U.S. Army Corps of Engineers (USACE). 2008. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-08-28. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- U.S. Army Corps of Engineers (USACE). 2010. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- U.S. Army Corps of Engineers (USACE). 2012. Regulatory program wetlands determination and delineation procedures for irrigated lands. *US Army Corps of Engineers. South Pacific Division*.
- Vepraskas, M. J., Craft, C. B., & Richardson, J. 2002. *Wetland soils: genesis, hydrology, landscapes, and classification*. Boca Raton, FL: CRC Press.
- Voldseth, R. A., W.C. Johnson., T. Gilmanov., G.R. Guntenspergen., and B.V. Millett. 2007. Model Estimation of Land-Use Effects on Water Levels of Northern Prairie Wetlands. *Ecological Applications*, 17(2):527-540.
- Whiles, M. R., and B.S. Goldowitz. 2001. Hydrologic Influences on Insect Emergence Production from Central Platte River Wetlands. *Ecological Applications*, 11(6):1829-1842.
- White, C. L., and M. B. Main 2005. Waterbird Use of Created Wetlands in Golf-Course Landscapes. *Wildlife Society Bulletin*, 33(2), 411-421.
- Wurster, F. C., D. J. Cooper., and W.E. Sanford. 2003. Stream/aquifer interactions at Great Sand Dunes National Monument, Colorado: influences on interdunal wetland disappearance. *Journal of Hydrology*, 271(1-4):77-100.

APPENDIX A: Partial list of technical sources searched as part of this literature review.

Agricultural Water Management
Ambio
American Journal of Agricultural Economics
American Midland Naturalist
BALWOIS 2010
Biodiversity and Conservation
Biological Conservation
Bridging the Gap
California Waterfowl Association.
Colonial Waterbirds
Conservation Biology
CRC Press
CRC Press
Critical Transitions in Water and Environmental Resources Management
Ecological Applications
Ecological Economics
Ecology
Ecosystems and Environment
Environmental and Resource Economics
Environmental Conservation
Environmental Management
Environmental Science & Technology
Forest Ecology and Management
Freshwater Biology
Geomorphology
Great Plains Research
Ground Water
Hydrobiologia
Hydrological Processes
Hydrological Sciences Journal
International Journal of Water Resources Development
International Water Management Institute
Journal Environmental Quality
Journal of Applied Ecology
Journal of Applied Forestry
Journal of Arid Environments
Journal of Environmental Management
Journal of Hydrology
Journal of Irrigation and Drainage Engineering
Journal of Louisiana Ornithology
Journal of Soil and Water Conservation
Journal of the American Water Resource Association
Journal of the Pennsylvania Academy of Science
Journal of Water Resources Development
Journal of Water Resources Planning and Management

Journal of Wildlife Management
Landscape Ecology
National Audubon Society
Natural Processes and Systems for Hazardous Waste Treatment
Pennsylvania Forest Resource Bulletin
Restoration Ecology
Reviews in Fisheries Science
South Pacific Division
Southeastern Naturalist
The Geographical Journal
University of California Press
University of Kansas, Museum Natural History Public Education Series University of Kansas,
Museum of Natural History Occasional Paper
USDA-ARS-WMU
Water and Science Technology
Water Resources Abstracts
Water Resources Bulletin
Water Resources Research
Waterbirds: The International Journal of Waterbird Biology
Wetlands
Wetlands Ecology and Management
Wetlands Engineering & River Restoration 2001
Wildlife Society Bulletin
Wisconsin Academy of Science, Arts and Letters
WMRS Symposium Volume 4
World Environmental and Water Resources Congress 2011

APPENDIX B: Citations relating to the ecology and management of irrigation induced wetlands.

1) Distribution/Geographic Range

An, S., H. Li, B. Guan., C. Zhou., Z. Wang., Z. Deng., Y. Zhi, Y. Liu, C. Xu, S. Fang, J. Jiang, and H. Li. 2007. China's Natural Wetlands: Past Problems, Current Status, and Future Challenges. *Ambio*, 36(4), 335-342.

Natural wetlands, occupying 3.8% of China's land and providing 54.9% of ecosystem services, are unevenly distributed among eight wetland regions. Natural wetlands in China suffered great loss and degradation (e.g., 23.0% freshwater swamps, 51.2% coastal wetlands) because of the wetland reclamation during China's long history of civilization, and the population pressure and the misguided policies over the last 50 years. Recently, with an improved understanding that healthy wetland ecosystems play a vital role in her sustainable economic development, China started major efforts in wetland conservation, as signified by the policy to return reclaimed croplands to wetlands, the funding of billions of dollars to restore degraded wetlands, and the national plan to place 90% of natural wetlands under protection by 2030. This paper describes the current status of the natural wetlands in China, reviews past problems, and discusses current efforts and future challenges in protecting China's natural wetlands.

Bartzen, B. A., K. W. Dufour, R. G. Clark, and F. D. Caswell. 2010. Trends in agricultural impact and recovery of wetlands in prairie Canada. *Ecological Applications*, 20(2):525-538.

Despite widespread recognition that they provide valuable ecosystem services and contribute significantly to global biodiversity, over half of the world's wetlands have been lost, primarily to agriculture. Wetland loss is evident in prairie Canada, but comprehensive information about causes of ongoing impact for existing wetlands is lacking. Habitat data collected for ~10 500 wetlands during annual waterfowl surveys (1985–2005) were analyzed using multistate models to estimate rates of wetland impact and recovery from agricultural activities in the Canadian prairies. An impact was defined as an agricultural activity that visibly altered a wetland margin (natural vegetation surrounding wetland interiors) or basin (interior depression capable of holding water), whereas recovery was deemed to have occurred if agricultural activities had ceased and effects were no longer visibly apparent. We estimated separate impact and recovery rates for wetland basins and wetland margins and considered covariates such as location, time, wetness indices, land use, and wetland permanence. Results indicate that impact rates for wetland margins have declined over time, likely due to a decreasing percentage of unaffected wetland on the landscape. Recovery rates for margins were always lower than impact rates, suggesting progressive incidence of impacts to wetlands over time. Unlike margins, impact and recovery rates for basins fluctuated with May pond densities, which we used as a wetness index. Shallow ephemeral wetlands located in agricultural fields had the highest impact and lowest recovery rates relative to wetlands with higher water permanence or situated in areas of lower agricultural intensity. High rates and incidence of wetland impact in conjunction with low recovery rates clearly demonstrate the need for stronger wetland protection in prairie Canada.

Agriculture; covariates; impact rates; multistate models; prairie Canada; recovery rates; wetlands.

Fennessy, S., and C. Craft. 2011. Agricultural conservation practices increase wetland ecosystem services in the Glaciated Interior Plains. *Ecological Applications*, 21(sp1):S49-S64.

The Glaciated Interior Plains historically supported a broad variety of wetland types, but wetland losses, primarily due to agricultural drainage, range from 50% to 90% of presettlement area. Wholesale land use change has created one of the most productive agricultural regions on earth, but wetland conversion has also led to the loss of the ecosystem services they provide, particularly water quality improvement, flood de-synchronization, carbon sequestration, and support of wetland-dependent species (biodiversity). Nearly three-quarters of the Glaciated Interior Plains fall within the Mississippi River drainage basin, where the combination of extensive tile drainage and fertilizer use has produced watersheds that contribute some of the highest nitrogen yields per acre to the Mississippi River. Wetland conservation practices implemented under Farm Bill conservation programs have established or involved management of nearly 110 000 ha of wetlands, riparian zones, and associated ecosystem services over the period 2000–2007. We estimated the cumulative ability of these conservation practices to retain sediment, nitrogen, and phosphorus in Upper Mississippi River Basin watersheds. Estimated retention amounts to 1.0%, 1.5%, and 0.8% of the total N, sediment, and P, respectively, reaching the Gulf of Mexico each year. If nutrient reduction is estimated based on the quantity of nutrients exported from the Glaciated Interior Plains region only, the numbers increase to 6.8% of N, 4.9% of P, and 11.5% of sediment generated in the region annually. On a watershed basis, the correlation between the area of wetland conservation practices implemented and per-hectare nutrient yield was 0.81, suggesting that, for water quality improvement, conservation practices are successfully targeting watersheds that are among the most degraded.

The provision of other ecosystem services such as C sequestration and biodiversity is less well studied. At best, implementation of wetland and riparian conservation practices in agricultural landscapes results in improved environmental quality and human health, and strengthens the rationale for expanding conservation practices and programs on agricultural lands.

Carbon sequestration; flood abatement; Glaciated Interior Plains, USA; nitrogen; U.S. Midwest; water quality improvement.

Garone, P. 2011. *The Fall and Rise of the Wetlands of California's Great Central Valley* (1 ed.). Berkeley, CA: University of California Press.

This is the first comprehensive environmental history of California's Great Central Valley, where extensive freshwater and tidal wetlands once provided critical habitat for tens of millions of migratory waterfowl. Weaving together ecology, grassroots politics, and public policy, Philip Garone tells how California's wetlands were nearly obliterated by vast irrigation and reclamation projects, but have been brought back from the brink of total destruction by the organized efforts of duck hunters, whistle-blowing scientists, and a broad coalition of conservationists. Garone examines the many demands that have been made on the Valley's natural resources, especially by large-scale agriculture, and traces the unforeseen ecological consequences of our unrestrained manipulation of nature. He also investigates changing public and scientific attitudes that are now ushering in an era of unprecedented protection for wildlife and wetlands in California and the nation.

Gollehon, N., and W. Quinby. 2000. Irrigation in the American West: Area, Water and Economic Activity. *International Journal of Water Resources Development*, 16(2), 187-195.

This article examines irrigation in the American West based on consistent Federal data sources. Irrigation is discussed using three measures: irrigated area, water use in irrigation, and the sales value of crops produced. We find that irrigation accounts for about three-quarters of the value of crops sold from about one-quarter of the harvested cropland in the West. In accomplishing the higher sales, irrigated agriculture accounts for three-quarters of the water withdrawn and most of the water use in the West.

Kath, J., A. LeBrocq, C. Miller 2010. Wetland hydrology in an agricultural landscape: implications for biodiversity. *BALWOIS 2010: Water Observation and Information System for Decision Support*, 25-29 May 2010, Ohrid, Macedonia.

Intensification of agricultural practices, such as groundwater extraction, stream flow regulation and vegetation clearing often leads to a reduction in both the number and hydrological diversity of wetlands in a landscape, reducing the amount of habitat available for many species. Remaining wetlands are often hydrologically homogenized and far less variable than under natural conditions and as consequence many species are no longer able to persist in the landscape over the long term. However, many studies only observe wetland hydrology at relatively small spatial and temporal scales. Consequently, there is little knowledge about wetland hydrology at the broader landscape scale and how it may change under changing climatic conditions. To help address this knowledge gap we analyzed hydrological data from 251 wetlands across 3 regions over a 17 year period from 1987 to 2005 to examine temporal changes in wetland hydrology in an agricultural landscape. This research investigated changes in the hydrological nature of wetlands in an agricultural landscape between two time periods from 1987-2005 and 2000-2005 (dry climatic period) to examine how wetlands may change through time, particularly under changing climatic conditions. In the recent time period, there was a significant change in the number of wetland hydrology groups represented in some of the landscapes. In the recent dryer period there was an increase in the number of frequently dry and wet wetlands and a reduction in the number of wetland representing the intermediate hydrological range. Changes in the number of wetland groups represented could have implications for biodiversity across the landscape if climate change intensifies the patterns observed.

Lemly, A. D., R.T. Kingsford., and J.R. Thompson. 2000. Irrigated Agriculture and Wildlife Conservation: Conflict on a Global Scale. *Environmental Management*, 25(5):485-512.

The demand for water to support irrigated agriculture has led to the demise of wetlands and their associated wildlife for decades. This thirst for water is so pervasive that many wetlands considered to be hemispheric reserves for waterbirds have been heavily affected; for example, the California and Nevada wetlands in North America, the Macquarie Marshes in Australia, and the Aral Sea in central Asia. These and other major wetlands have lost most of their historic supplies of water and some have also experienced serious impacts from contaminated subsurface irrigation drainage. Now mere shadows of what they once were in terms of biodiversity and wildlife production, many of the so-called "wetlands of international importance" are no longer the key conservation strongholds they were in the past. The conflict between irrigated agriculture and wildlife conservation has reached a critical point on a global scale. Not only has local wildlife suffered, including the extinction of highly insular species, but a ripple effect has impacted migratory birds worldwide. Human societies reliant on wetlands for their livelihoods are also bearing the cost. Ironically, most of the degradation of these key wetlands occurred during a period of time when public environmental awareness and scientific assertion of the need for wildlife conservation was

at an all-time high. However, designation of certain wetlands as "reserves for wildlife" by international review boards has not slowed their continued degradation. To reverse this trend, land and water managers and policy makers must assess the true economic costs of wetland loss and, depending on the outcome of the assessment, use the information as a basis for establishing legally enforceable water rights that protect wetlands from agricultural development.

Tiner, R. W. 2002. Wetland indicators: A guide to wetland identification, delineation, classification, and mapping. CRC Press.

Understand the current concept of wetland and methods for identifying, describing, classifying, and delineating wetlands in the United States with Wetland Indicators - capturing the current state of science's role in wetland recognition and mapping. Environmental scientists and others involved with wetland regulations can strengthen their knowledge about wetlands, and the use of various indicators, to support their decisions on difficult wetland determinations. Professor Tiner primarily focuses on plants, soils, and other signs of wetland hydrology in the soil, or on the surface of wetlands in his discussion of Wetland Indicators. Practicing - and aspiring - wetland delineators alike will appreciate Wetland Indicators' critical insight into the development and significance of hydrophytic vegetation, hydric soils, and other factors.

2) Regulatory Status

Curry, R. R. 1992. WMRS Symposium Volume 4: The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. University of California, White Mountain Research Station

The Lahontan Regional Water Quality Control Board, the California Energy Commission, and Mono County have solicited detailed wetland delineation and mapping in a test area of the Bridgeport Valley. The focus of the 1991 work by the University of California, the Soil Conservation Service (SCS), and the Sacramento-based consulting firm of EIP Associates is on an area of both natural and irrigation-induced wetlands, much of which have been heavily grazed for the past 130 years. Alkali-seep hot springs, tourist visitor use, and the Bridgeport townsites all further complicate the tasks of wetland delineation. A 6 sq mi area (15.5 sq km) was mapped using standard wetland delineation methods for soils, hydrology, and vegetation at a mapping scale sufficient to define wetland units approximately 100ft x 100ft (30m x 30m) or larger. This detailed wetland delineation as well as equally detailed SCS soil mapping was done by separate teams on the same scale base and later compared to evaluate independent criteria for wetland delineation. During the course of the study, the federal rules for wetland delineation were retroactively changed. Jurisdictional wetlands have not been defined and administered as waters of the State of California, but are now coming under state purview. Federal agencies in charge of protecting wetlands in the absence of state programs have not always agreed with local and state agencies and among themselves on the knotty issues of human-induced wetlands. Standard methods based upon site hydrology are difficult to define in times of prolonged drought. Methods using obligate and facultative wetland plant species are also commonly not available in times of drought and are especially difficult where sustained grazing has thoroughly altered potential natural vegetation. Wetland soil types are difficult to define in the field in alkali sites or in sites where cold climate and extremely slow soil development minimize the lasting effects of seasonal reducing conditions in a soil profile. This study explored these problems in a geographic area typical of much of the eastern Sierra Nevada meadowland and high-desert basin

seeps. Suggested options for delineation in a time of potential weakening of federal oversight are explored in the context of irrigation-induced microclimate change, grazing-regulated changes in evapotranspirative demand, and the roles of natural and introduced vertebrate populations.

Department of Ecology. 2010. Focus on Irrigation-Influenced Wetlands. *State of Washington Department of Ecology*.

Much of the deep-soil native habitats in eastern Washington have been converted to agriculture. A large portion of this land, particularly in the Columbia River Basin, is under irrigation. Additionally, some agricultural areas in western Washington are also irrigated. In many areas, the regional groundwater table is higher than it was before irrigation. Many wetlands have formed adjacent to irrigation conveyance systems and in low-lying areas where irrigation occurs. Some confusion exists as to whether these wetlands are considered "jurisdictional" – that is, whether they are regulated under federal, state, or local laws. This focus sheet explains how wetlands in irrigation areas are regulated under Washington state law. Applicable provisions of federal or local laws are not addressed by this document. *Consult with the U.S. Army Corps of Engineers for applicability of federal law and your local city or county planning department for applicability of local laws.*

Environmental Laboratory. 1987. Corps of Engineers Wetland Delineation Manual. *US Army Corps of Engineers. Wetland Research Program Technical Report Y-87-1.*

Recognizing the potential for continued or accelerated degradation of the Nation's waters, the U.S. Congress enacted the Clean Water Act (hereafter referred to as the Act), formerly known as the Federal Water Pollution Control Act (33 U.S.C. 1344). The objective of the Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Section 404 of the Act authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into the waters of the United States, including wetlands. The purpose of this manual is to provide users with guidelines and methods to determine whether an area is a wetland for purposes of Section 404 of the Act.

U.S. Army Corps of Engineers. 2008. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region (Version 2.0)*, ed. J. S. Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-08-28. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual (hereafter called the Corps Manual). The Corps Manual provides technical guidance and procedures, from a national perspective, for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act (33 U.S.C. 1344) or Section 10 of the Rivers and Harbors Act (33 U.S.C. 403). According to the Corps Manual, identification of wetlands is based on a three-factor approach involving indicators of hydrophytic vegetation, hydric soil, and wetland hydrology. This Regional Supplement presents wetland indicators, delineation guidance, and other information that is specific to the Arid West Region.

U.S. Army Corps of Engineers. 2010. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region (Version 2.0)*, ed. J. S.

Wakeley, R. W. Lichvar, and C. V. Noble. ERDC/EL TR-10-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

This document is one of a series of Regional Supplements to the Corps of Engineers Wetland Delineation Manual (hereafter called the Corps Manual). The Corps Manual provides technical guidance and procedures, from a national perspective, for identifying and delineating wetlands that may be subject to regulatory jurisdiction under Section 404 of the Clean Water Act (33 U.S.C. 1344) or Section 10 of the Rivers and Harbors Act (33 U.S.C. 403). According to the Corps Manual, identification of wetlands is based on a three-factor approach involving indicators of hydrophytic vegetation, hydric soil, and wetland hydrology. This Regional Supplement presents wetland indicators, delineation guidance, and other information that is specific to the Western Mountains, Valleys, and Coast Region.

U.S. Army Corps of Engineers. 2012. Regulatory program wetlands determination and delineation procedures for irrigated lands. *US Army Corps of Engineers. South Pacific Division*.

In accordance with the 1986 preamble to 33 CFR Part 328.3 (51 FR 41217), the Corps generally does not consider artificially irrigated areas which would revert to uplands if the irrigation ceased to be waters of the United States under Section 404 of the Clean Water Act. To determine whether irrigated land, or a portion of irrigation land, is a wetland under 33 CFR 328.3(b), the Corps must first determine whether the irrigated land, under normal circumstances, exhibits the three factors for wetland identification and delineation provided in the 1987 Manual, or the applicable criteria in Chapter 5 of the appropriate regional supplement. Conducting a wetland determination or delineation in accordance with the 1987 manual and the indicators, guidance, and procedures provided in the appropriate regional supplement is critical for determining the extent and location of wetlands on the site. Due to the complexity of these circumstances in irrigated areas, and the need for rigorous documentation, a comprehensive determination, as described in the 1987 Manual, will generally be necessary unless the wetland boundaries are obvious. For areas greater than five acres, transects will normally be required.

3) Wetland Creation in Agricultural Landscapes

Abney, C. 2011. Designing Wetlands for Wildlife *Wetlands Engineering & River Restoration* 2001 , 1-6.

One of the most overstated yet least understood wetland benefits is wildlife habitat. The ecological requirements for productive wetland habitat is complex, and recreating or simulating a biologically diverse system is a tremendous challenge. If wildlife habitat is truly a project objective, then consideration for these needs must be incorporated at the design stage. Often the wildlife component is left to chance, whereby the designer simply assumes wildlife will benefit from the project. Just as natural systems may favor a particular group of wildlife over another, restored or created systems may provide habitat for some water dependent species while excluding others. The manner in which a wetland is constructed and managed will make it more or less conducive to select types of wildlife. The designer should have a "targeted" wildlife species or group in mind that will benefit from the new habitat.

Adamus, P.R. 1993. Irrigated Wetlands Of The Colorado Plateau: Information Synthesis And Habitat Evaluation Method.

Wetlands of the Colorado Plateau that receive water from irrigation can, by their functions, support several societal values. For example, their capacity for removing nitrate and perhaps pesticides from nonpoint source runoff might be considerable. However, relatively little research has been conducted in irrigated wetlands, and their ability to alter water quality in particular remains relatively unknown. Much more documentation exists concerning the importance of irrigated wetlands as habitat. About 72% of all reptiles, 77% of all amphibian species, 80% of all mammals, and 90% of all bird species which occur regularly in the Colorado Plateau region routinely use irrigated wetlands and riparian areas. About 30% of the region's bird species use wetlands and other aquatic areas to the exclusion of upland habitats. Wetland and riparian habitats also support a disproportionate number of species that are of concern because they migrate to neotropical areas, have small continental populations, or are declining. Virtually all wetland and riparian habitats in agricultural areas of the Colorado Plateau are sustained to some degree by runoff and seepage from irrigation.

Bergquist, R., J. Monk, D. Priske, and Y. Au Yeung. Stockton BNSF Intermodal Facility Wetland Mitigation *Wetlands Engineering & River Restoration* 2001.1-11.

The construction of an Intermodal Facility four miles east of Stockton, California in 2000, impacted approximately 1.72 acres of waters of the United States that were further classified as wetlands. These wetlands also supported a State and Federal threatened snake species, the giant garter snake (*Thamnophis gigas*). To compensate for impacts to waters of the United States and the giant garter snake, new wetlands were designed and built in the summer of 2000 on a portion of the Intermodal Facility site later named the Littlejohns Creek Mitigation Preserve. Regulatory permit applications prepared by Monk & Associates (M&A) provided the specific locations, design criteria, and guidelines for the development of 5.16 acres of compensation wetlands. Using the design criteria, DMJM+HARRIS (Long Beach, CA) and ECI the Water Resource Division of DMJM+HARRIS designed and engineered the mitigation wetlands, prepared the bid package, and participated in the construction of the wetlands within the preserve. The 56 acre Littlejohns Creek Mitigation Preserve was established at the southeastern end of the Intermodal Facility project site.

Four pools were connected by new channels to the existing Littlejohns Creek stream channel within. The creation of the new wetlands are the focus of this paper. Major design components included an inlet weir structure that diverts flows from Littlejohns Creek into two mitigation channels. These channels also convey flows to four side pools that retain water within the mitigation preserve. Success keys are the flow control structures and the regulatory agency success criteria established for creation of the new waters of the United States.

Call, J., C. 2001. Comparative Values of Wetlands Located near Salt Lake City, Utah *Bridging the Gap*, 1-10.

This paper compares the functional values of existing natural and constructed wetlands with the wetlands that will be filled during construction of the proposed Legacy Highway near Salt Lake City, Utah. Wetland impact along the proposed highway alignment is the most important issue considered in the project Environmental Impact Statement (EIS). This paper proposes a reconnaissance level method by which the Legacy wetlands were compared with six other wetlands, namely, the Salt Lake City wastewater treatment plant wetland (WWTP), Airport and Kennecott mitigation wetlands, Farmington Bay, Murray City Jordan River Parkway wetland and a high elevation natural wetland. Relative ratings for the functional values for each wetland site were

developed based on reconnaissance level observations made during October and November 1998. Evaluations of the Legacy Highway wetlands indicate that their functional values are not as high as the other sites observed. The northern Legacy wetlands were given a medium value and the southern Legacy wetlands a low value. The comparison wetland sites considered were mostly rated high. The rating system indicated that flood control and groundwater protection were not significant functional values for these wetlands. Water quality and habitat were the most important values.

Crifasi, R. 2005. Reflections in a Stock Pond: Are Anthropogenically Derived Freshwater Ecosystems Natural, Artificial, or Something Else? *Environmental Management*, 36(5):625-639.

For millennia, people have altered freshwater ecosystems directly through water development and indirectly by global change and surrounding land-use activities. In these altered ecosystems, human impacts can be subtle and are sometimes overlooked by the people who manage them. This article provides two case studies near Boulder, Colorado that demonstrate how perceptions regarding these ecosystems affect their management. These examples are typical of lakes and streams along the Front Range of Colorado that are simultaneously natural and social in origin. Although natural, many of the region's freshwater ecosystems are affected by ongoing ecologic, hydrologic, chemical, and geomorphic modifications produced by human activity. People and nature are both active participants in the production of these freshwater ecosystems. The concept of "hybridity," borrowed from geographers and social scientists, is useful for describing landscapes of natural and social origin. Hybrid freshwater ecosystems are features of the humanized landscape and are derived from deliberate cultural activities, nonhuman physical and biological processes, and incidental anthropogenic disturbance. Our perceptions of "natural" freshwater ecosystems and what definitions we use to describe them influences our view of hybrid systems and, in turn, affects management decisions regarding them. This work stresses the importance of understanding the underlying societal forces and cultural values responsible for the creation of hybrid freshwater ecosystems as a central step in their conservation and management.

Ekstein, J. D., S. Hygnstrom. 1996. Fate of Wetlands Associated with the Central Nebraska Irrigation Canal System. *Great Plains Research*, 6:41-60.

Changes in wetlands in the vicinity of the Phelps and £65 canals operated by Central Nebraska Public Power and Irrigation District in Southcentral Nebraska were examined using aerial photographs taken on seven occasions from 1938 to 1981. According to previous research, nearly 90% of the original wetlands within the surrounding Rainwater Basin were destroyed or altered by draining and filling between 1900 and 1980. Within a zone extending 10 kilometers on each side of the Phelps and £65 canals, however, we observed an increase in the number and total area of wetlands, which we hypothesize to have been caused by an elevated groundwater table. Of additional importance for wildlife management, there was a notable decrease in wetlands temporarily flooded for 2 months or less, and a notable increase in wetlands seasonally flooded for 3 to 5 months each year. These changes were most conspicuous after 1969.

Galbraith, H. A., Priyanie; A. Huber-Lee 2005. The effects of agricultural irrigation on wetland ecosystems in developing countries: a literature review *Comprehensive Assessment of Water Management in Agriculture Discussion Paper 1. International Water Management Institute (IWMI), Comprehensive Assessment Secretariat.*

The purpose of this review was to evaluate the extent to which the current scientific literature allows us to determine and quantify the ecological costs and benefits of irrigated agriculture in wetland ecosystems of the developing countries, and to establish quantitative relationships between anthropogenic activities and ecological responses. The following are the main points that emerged: Irrigation or activities associated with agricultural irrigation can and do cause adverse impacts to wetland ecological resources ranging from localized and subtle, to long-distance and severe. Irrigation or activities associated with irrigation can also result in the creation or enhancement of important wetland ecological resources. Depending on the irrigation activity and scale, irrigated agriculture and ecological resources can sustainably coexist. The confounding effects of “natural” or other anthropogenic stressors are not often evaluated when the effects of irrigation on wetlands are being assessed, and it can be difficult to partition the effects due to irrigation. The potential long-term ecological benefits of water storage schemes are rarely investigated. Any measurement of impact usually stops once the project is implemented. Because of the above (bullets 4 and 5), “quantitative” information on the relationships between irrigated agricultural activity and ecological effects is sparse to non-existent. This severely impairs our ability to learn from previous failures or successes and, importantly, to design future activities and projects so as to minimize environmental impacts. If we are to minimize the potential for ecological injury and enhance the likelihood of benefits in future projects, it is crucial that the existing data base be enormously expanded. Specifically, we need to treat each new project and scheme as a “natural experiment” where the ecological resources and effects are quantified from before the project is implemented until long after implementation. Until this is accomplished, we run the risk of repeating the same mistakes that have been made in the past.

Hibbs, B.,M. Kelliher, and N. Erdelyi. 2011. Use of Environmental Isotopes to Determine Impacts on Wetlands Due to Lining of Irrigation Canals, Salton Sea Area, California *World Environmental and Water Resources Congress 2011*,1064-1074.

The All American Canal and its Coachella Branch divert water from the Colorado Rivers for use in the Imperial and Coachella Valleys. On the northeast side of the Salton Trough, leakage from the unlined Coachella Canal recharged local aquifers. Wetlands have expanded due to spring discharge below the canal. Wetlands were natural features prior to canal construction, but their areal extent has increased substantially due to leakage from Coachella Canal. Lining of the entire canal was completed in early 2007. Before and after the canal was lined, we collected samples from several spring and well locations down gradient from Coachella Canal to assess geochemical and isotopic signatures for comparison to canal and native groundwater sources. Analysis of stable isotopes of oxygen and hydrogen identifies three distinct groups of water. One group consists of nearly pure canal water, a second group consists of nearly pure native groundwater, and a third group consists of various mixtures of canal and native groundwater. Most of the waters at the preserve are derived from Colorado River-fed canal water. Tritium and Carbon-14 support these interpretations, while simultaneously providing age-dates of local groundwater. Now that lining of the canal has been completed, flow at the wetlands will decrease. As flow decreases the isotopic and hydrochemical signature of the waters could evolve toward that of native groundwater; this evolution will be a direct result of decreased recharge from the Coachella Canal. A wetland mitigation project has been developed using artificial recharge to maintain adequate flow at the springs, but artificial recharge will amount to no more than 15 to 20% of the canal leakage that occurred before the canal was lined. Continued monitoring of these locations are being done to determine the effects of lining on the current wetland areas.

Moreno-Mateos, D., C. Pedrocchi, and F. Comín 2009. Avian communities' preferences in recently created agricultural wetlands in irrigated landscapes of semi-arid areas. *Biodiversity and Conservation*, 18(4), 811-828.

Numerous wetlands have been created spontaneously in the Ebro river basin as a consequence of new irrigation developments over the last 50 years. Water used for irrigating farmland drains into the lower parts of small valleys to form wetlands that are mostly dominated by common reed (*Phragmites australis*). Bird communities established in these wetlands are still simple, partly due to the lack of management to enable their ecological functions to improve. A knowledge of which environmental features favor these bird communities is essential in order to improve the design of newly created or restored wetlands associated to future irrigation developments. For this purpose, the habitat and vegetation features of 15 wetlands have been sampled. The structure of bird communities (richness, abundance and diversity) was monitored over 3 years during the breeding season and in winter at foraging and nocturnal roosting. The presence of bushes, height of stems and distance from large wetlands (>1 ha) proved to be the most influential variables on bird community structure and on most abundant species during the breeding season. Wetland area and compactness influenced species richness and the most abundant species during winter foraging and roosting. There was a maximum stem height at which only reed-dwelling birds remained. Uncontrolled winter burning had a severe negative effect upon these recently established populations. The ecological functions of newly created or restored wetlands, including those for run-off treatment in agricultural catchments, could be substantially improved taking into account simple guidelines from these results which relate bird community characteristics to wetland features.

Waterbirds; Winter birds; Mediterranean; *Phragmites australis*; Winter burning

Sueltenfuss, J., D. Cooper, R. Knight, and R. Waskom. 2013. The Creation and Maintenance of Wetland Ecosystems from Irrigation Canal and Reservoir Seepage in a Semi-Arid Landscape. *Wetlands*, 33(5):799-810.

Irrigation has increased agricultural productivity in the arid American West, and has greatly altered the natural landscape. This study sought to identify the hydrologic processes linking irrigation canals and reservoirs to wetlands. We mapped wetlands within an irrigation company service area in northern Colorado, measured groundwater levels, and used stable oxygen isotopes to identify groundwater sources. We related vegetation composition in study wetlands to environmental variables to identify the types of wetlands supported by leakage from irrigation conveyance and storage structures. Ninety-two percent of wetlands were visually connected to the irrigation infrastructure. Wetland water tables varied with adjacent canal flow, and isotopic data indicated that wetlands within the study area were recharged solely by canal leakage. Wetland vegetation composition was related to both soil salinity and groundwater depth. Salt flats formed in areas with high salinity, marsh communities in areas with low salinity and higher standing water, and meadow communities in areas with low salinity and water tables near the ground surface. Though land conversion and water diversions have led to dramatic reductions in historic wetland area in some places, it is clear from our study that current agricultural landscapes create wetlands that rely on irrigation water.

Keywords Irrigation; Canal seepage; Wetlands

Sueltenfuss, J. 2012. The ecology of an irrigation system: wetland creation in an agricultural landscape MS thesis, Colorado State University.

Irrigation has increased the agricultural productivity of the arid American West, but has also greatly altered the natural landscape. Irrigation canals transport water to 17 million ha of currently irrigated land. Because water is a limited resource in the west, and irrigated agriculture uses approximately 90% of all the water diverted from rivers, much attention has been paid to the efficiency of irrigation systems. Irrigation canals have been shown to leak up to 50% of the water they transport, affecting both groundwater recharge and return flows to rivers, though little work has been done documenting the ecological effects of irrigation canal seepage on wetland ecosystems. This study sought to identify the hydrologic processes linking canals and reservoirs to wetlands, identify the types of wetlands supported by irrigation canal seepage, and document the area of wetlands supported by irrigation within the service area of an irrigation company. All wetlands within the North Poudre Irrigation Company service area in Larimer County were mapped and their hydrologic source determined from visual clues. Groundwater monitoring wells were installed in wetlands adjacent to canals and reservoirs to identify the hydrologic influence of canal seepage on wetland hydrologic regime. To further demonstrate the hydrologic source of wetlands, stable oxygen isotopes were analyzed within wetlands and possible adjacent water sources. Vegetation characteristics and species percent composition was related to environmental variables to highlight the types of wetlands supported by an irrigation infrastructure. A total of 176 wetlands covering 652 ha were mapped, 92% of which were visually connected to the irrigation infrastructure. Wetland water tables fluctuated with adjacent canal flow, with increases in the water table when canals started transporting water, and decreases in water table depth during times when canals did not carry water. Isotopic data indicate that canal leakage is the hydrologic source for adjacent wetlands within the study area. The isotopic signature of canal water matched that of wetlands closer to canals, with evaporatively enriched isotopic signatures in wetlands further from canals. Wetland vegetation composition was related to both salinity and groundwater depth, with salt flats dominated by *Atriplex spp.* forming in areas with high salinity, marsh communities dominated by *Typha latifolia* and *Schoenoplectus acutus* forming in areas with low salinity and deeper standing water, and meadow communities dominated by *Carex nebrascensis* and *Schoenoplectus pungens* forming in areas with low salinity and water tables closer to the ground surface. Though land conversion and water diversions have led to dramatic reductions in historic wetland area in some places, it is clear from this study that current agricultural landscapes create wetlands that rely on excess irrigation water for their hydrologic maintenance. Any future changes in irrigation practices or water distribution may have negative consequences on wetland ecosystems.

4) Habitat, Threatened and Endangered Species

Bergquist, R., J. Monk., D. Priske, and Y. Au Yeung. Stockton BNSF Intermodal Facility Wetland Mitigation *Wetlands Engineering & River Restoration 2001*, 1-11.

The construction of an Intermodal Facility four miles east of Stockton, California in 2000, impacted approximately 1.72 acres of waters of the United States that were further classified as wetlands. These wetlands also supported a State and Federal threatened snake species, the giant garter snake (*Thamnophis gigas*). To compensate for impacts to waters of the United States and the giant garter snake, new wetlands were designed and built in the summer of 2000 on a portion of the Intermodal Facility site later named the Littlejohns Creek Mitigation Preserve. Regulatory

permit applications prepared by Monk & Associates (M&A) provided the specific locations, design criteria, and guidelines for the development of 5.16 acres of compensation wetlands. Using the design criteria, DMJM+HARRIS (Long Beach, CA) and ECI the Water Resource Division of DMJM+HARRIS designed and engineered the mitigation wetlands, prepared the bid package, and participated in the construction of the wetlands within the preserve. The 56 acre Littlejohns Creek Mitigation Preserve was established at the southeastern end of the Intermodal Facility project site.

Conway, W. C., L.M. Smith, and J.D. Ray 2005. Shorebird Breeding Biology in Wetlands of the Playa Lakes, Texas, USA. *Waterbirds: The International Journal of Waterbird Biology*, 28(2):129-138.

Wetlands in the Playa Lakes Region of Texas are important habitats for North American wintering waterfowl and migrant shorebirds. However, shorebird breeding biology has been overlooked in characterizing the region's ecological importance. In 1998 and 1999, American Avocet (*Recurvirostra americana*), Black-necked Stilt (*Himantopus mexicanus*), Killdeer (*Charadrius vociferous*), and Snowy Plover (*C. alexandrinus*) breeding ecology were studied in playas, saline lakes, and riparian wetlands in the Playa Lakes Region of Texas. Chronology of nest initiation, clutch sizes, and hatching success for 298 Snowy Plover, 111 American Avocet, 43 Killdeer, and 26 Black-necked Stilt clutches were measured. All four species nested in saline lakes, American Avocet and Killdeer also nested in playas, and Snowy Plover nested on riparian wetlands. American Avocet had higher hatching success in 1999 (52%) than 1998 (8%), because of more suitable hydrological conditions and lower predation. Hatching success was higher in 1998 than 1999 for Killdeer (1998, 63%; 1999, 21%) and Snowy Plover (1998, 47%; 1999, 33%) due to failures caused by flooding and hail in 1999. In other regions, clutch predation limits shorebird productivity, but hatching success in the Playa Lakes Region appears to be limited by unpredictable precipitation patterns and wetland hydroperiod. As such, breeding shorebird conservation and management should focus upon maintaining wetland hydrological integrity.

American Avocet, Black-necked Stilt, Breeding Biology, Killdeer, Playas, Playa Lakes Region of Texas, Saline Lakes, Snowy Plover.

Czech, H. A., and K.C. Parsons. 2002. Agricultural Wetlands and Waterbirds: A Review. *Waterbirds: The International Journal of Waterbird Biology*, 25(ArticleType: research-article / Issue Title: Special Publication 2: Managing Wetlands for Waterbirds: Integrated Approaches / Full publication date: 2002 / Copyright © 2002 Waterbird Society), 56-65.

Waterbird use of agricultural wetlands has increased as natural wetlands continue to decline worldwide. Little information exists on waterbird use of wetland crops such as taro, hasu, and wild rice. Several reports exist on waterbird use of cranberry bog systems. Information exists on waterbird use of rice fields, especially by herons and egrets. Rice fields encompass over 1.5 million km² of land and are found on all continents except Antarctica. Rice fields are seasonally flooded for cultivation and to decoy waterfowl, and drawn down for sowing and harvest. A wide variety of waterbirds including wading birds, shorebirds, waterfowl, marshbirds, and seabirds utilize rice fields for foraging and to a lesser extent as breeding sites. In some areas, especially Asia, waterbirds have come to rely upon rice fields as foraging sites. However, few reports exist on waterbird use of rice ecosystems outside of the Mediterranean Region. Species that are commonly found utilizing agricultural wetlands during the breeding season, migration, and as wintering

grounds are listed. General trends and threats to waterbirds utilizing agricultural wetlands, including habitat destruction and degradation, contaminant exposure, and prey fluctuations are presented.

Agricultural wetlands, waterbirds, rice, cranberries, habitat, foraging.

Day, J. H. C. M. A. 1998. Water bird communities in rice fields subjected to different postharvest treatments. . *Colonial Waterbirds*, 21, 185-197.

In California's Sacramento Valley, the potential value of rice fields as habitat for waterbirds may vary with harvest method, post-harvest treatment of rice straw (chopped, burned, plowed), and extent of flooding. Recent changes in rice harvesting methods (i.e., use of stripper-headers) and a legislative mandate to decrease burning of rice straw after harvest may alter habitat availability and use. Thus, we investigated species richness and community composition of nonbreeding waterbirds during October-March 1993-94 and 1994-95 in rice fields of the northern Sacramento Valley. Most (85-91% of land area) rice was conventionally harvested (i.e., cutter bar), and the remainder was stripped. Rice straw was left untreated in more than half of fields (52% in 1994 and 54% in 1995), especially in stripped fields (56-70%). In fields where farmers treated straw, the most common management methods were plowing (15-21%), burning (19-24%), and chopping (3-5%). Fields became increasingly wet from October through March as seasonal precipitation accumulated and farmers flooded fields to facilitate straw decomposition and provide habitat for ducks. Species richness of waterbirds was greater ($P < 0.002$) in conventionally-harvested fields than in stripped fields; within harvest methods, species richness was consistently greater ($P < 0.01$) in flooded than non-flooded fields. By contrast, species richness did not differ among straw treatments ($P > 0.23$). Species richness in stripped fields probably was low because foraging opportunities were limited by tall dense straw, decreased grain density, and infrequent flooding. We recommend that land managers wishing to provide habitat for a diverse waterbird community harvest rice using conventional methods and flood fields shallowly.

Elphick, C. S. 2000. Functional equivalency between rice fields and seminatural wetland habitats. *Conservation Biology*, 14(1), 181-191.

Evaluating the potential for anthropogenic habitats to act as surrogates for the natural habitats they replace is a key issue in conservation biology. In California, flooded rice fields are used by numerous aquatic birds during winter. If this habitat functions similarly to more natural wetlands, increased flooding may help replace the extensive wetlands that occurred in the region prior to agricultural development. I tested whether food abundance, perceived predation threat, foraging performance, and the way in which birds allocate their time to different behaviors differed between flooded rice fields and semi natural wetlands for several species of aquatic bird. When appropriate, I also compared flooded and unflooded fields. Invertebrate densities did not differ among habitats. Semi natural wetlands had less rice grain but more seeds from other plants than the two rice habitats. The frequency with which predators passed over a feeding area was low in flooded fields than in unflooded fields or semi natural wetlands. Most differences in feeding performance and time allocation among habitats were small and statistically insignificant. For some species, feeding efficiency was greater in semi natural wetlands than in flooded fields. Increasing attack rates and the amount of time spent feeding when in flooded fields, however, may allow birds to compensate for reduced efficiency. Multivariate analyses showed that group size, predation threat, time of day, date, and water depth often were associated with behaviors, but that these variables

rarely accounted for habitat differences. Flooded fields apparently provide equivalent foraging habitat to semi natural wetlands and, because of reduced predation threat, may be a safer habitat for waterbirds. Thus, if managed appropriately, one of the world's dominant forms of agriculture can provide valuable waterbird habitat.

Erwin, R. M., M. Coulter, and H. Cogswell. 1986. The Use of Natural vs. Man-Modified Wetlands by Shorebirds and Waterbirds. *Colonial Waterbirds*, 9(2), 137-138.

The loss of wetlands continues world-wide. The impact especially has been felt in coastal areas, but water management elsewhere has resulted in marked reductions of aquatic bird populations. Concern for wetland management led to the convocation of a symposium on waterbird and shorebird use of natural and man-modified wetlands in December 1985 at the first joint meeting of the Colonial Waterbird Group and the Pacific Seabird Group. Contributions discussed a wide cross-section of taxa, geographic area, wetland type, and level of approach. Coverage included North America, South America, and Europe.

Aquatic ecosystems, avian ecology, conservation, management, waterbirds, shorebirds, wetlands

Erwin, R. M. 2002. Integrated Management of Waterbirds: Beyond the Conventional. *Waterbirds: The International Journal of Waterbird Biology*, 25, 5-12.

Integrated waterbird management over the past few decades has implicitly referred to methods for managing wetlands that usually attempt to enhance habitat for taxonomic groups such as shorebirds and wading birds, in addition to waterfowl, the traditional focus group. Here I describe five elements of integration in management: taxonomic, spatial, temporal, population and habitat, and multiple-use management objectives. Spatial integration simply expands the scale of management concern. Rather than emphasizing management on a very limited number of impoundments or wetlands in small refuges or wildlife management areas, the vision is beginning to shift to connectivity within larger landscapes on the order of many square kilometers as telemetry data on daily and seasonal movements for many species become available. Temporal integration refers to the potential for either simultaneous management for waterbirds and commercial "crops" (e.g., crayfish and rice) or for temporally-staggered management such as row crop production in spring-summer growing seasons and waterbird management on fallow fields in the non-growing (winter) season. Integrating population dynamics with habitats has become a major research focus over the past decade. Identifying which wetlands are "sources" or "sinks" for specific populations provides managers with critical information about effective management. Further, the applications of spatially explicit population models place heavy demands on researchers to identify use patterns for breeding and dispersing individuals by age, sex, and reproductive class. Population viability analysis models require much the same information. Finally, multiple-use management integration refers to trying to optimize the uses of wetlands, when only one (perhaps secondary) use may include waterbird management. Depending upon the ownership and primary land use of a particular parcel of land containing wetlands and/or water bodies, managing for waterbirds may be an "easy sell" (e.g., public natural resource lands) or a very contentious one, where wetlands are created for industrial, aquaculture or urban uses. In the latter case, careful planning and implementation require broad stakeholder participation and education.

Impoundments, landscape scale, refuges, shorebirds, wading birds, wetland and waterbird management, waterfowl.

Fasola, M., and X. Ruiz. 1996. The Value of Rice Fields as Substitutes for Natural Wetlands for Waterbirds in the Mediterranean Region. *Colonial Waterbirds*, 19, 122-128.

The natural wetlands of the Mediterranean have been reduced to 10-20% of their original area over the past few centuries. However, the rice fields that have supplanted them in some regions may be valuable habitats for waterbirds. We describe the use of rice fields by waders, gulls, terns, ducks and herons in Italy, Spain, France, Greece and Portugal where this cultivation is most prevalent in certain restricted areas. Rice field systems, including the irrigation canals, are used by a variety of waterbirds, primarily as feeding habitats, and to a lesser extent as breeding sites. The long duration of flooding allows waterbird use through winter in Spain and France; it is limited to spring in other regions. However, the heavy dependence of waterbirds on rice fields is hazardous, because rice cultivation is subject to suddenly changing agricultural practices. Threats include risk from pesticide contamination, changes in the management of rice cultures, the rapidly spreading practice of cultivating rice on dry fields, and from large-scale hydrological changes. We urge authorities to recognize the importance of rice fields for the conservation of Mediterranean waterbirds and propose that cultivation and bird conservation issues be addressed in a holistic fashion.

Gray, M. J., L. M. Smith, and R. Brenes. 2004. Effects of Agricultural Cultivation on Demographics of Southern High Plains Amphibians. *Conservation Biology*, 18(5), 1368-1377.

Anthropogenic disturbance of landscapes surrounding wetlands is considered a factor in local and global amphibian declines. Few data exist on the effects of agricultural cultivation of wetland watersheds on amphibians, and results from previous studies are contradictory. Our objective was to test the effects of general anthropogenic land use (cultivation vs. grassland) on the demographics of seven species and three age classes of amphibians in the Southern High Plains of Texas. We partially enclosed 16 playa wetlands (4 per land use per year) with drift fences and pitfall traps and monitored relative daily abundance and diversity from 16 May to 17 October 1999 and 19 April to 18 August 2000. In general, relative abundance (i.e., average daily capture) of New Mexico and plains spadefoots (*Spea multiplicata*, *S. bombifrons*) was greater at cropland than grassland playas; the abundance of other species and diversity of the amphibian assemblage was not affected by land use. Also, abundance generally was greater in 1999 than 2000 for metamorph spadefoots and barred tiger salamanders (*Ambystoma tigrinum mavortium*). Differences in spadefoot abundance between land-use types may have been related to low species-specific vagility, resulting in increased nestedness within disturbed landscapes and reduced abundance of a potential keystone intraguild predator in cropland playas. The yearly difference in amphibian abundance was likely related to annual precipitation, which influenced wetland hydroperiod. Agricultural cultivation surrounding wetlands is associated with the increased abundance of some amphibian species, but other demographic and fitness parameters-such as temporal demographics, body size, and diet diversity-may be negatively affected.

Huner, J. V., J.W. Clinton, and W. Norling. 2002. Managing Agricultural Wetlands for Waterbirds in the Coastal Regions of Louisiana, U.S.A. *Waterbirds: The International Journal of Waterbird Biology*, 25: 66-78.

Rice and/or crawfish are cultivated in over 225,000 ha of shallow earthen impoundments within 160 km of the Gulf of Mexico along the coast of Louisiana. The region includes both the Gulf Coastal Plain and Prairie and the Lower Mississippi River Valley. Annual loss of 4,475 ha of coastal wetlands in Louisiana due to subsidence, erosion, and rising sea level has significantly reduced desirable freshwater habitat in the region. The suite of resident, migrant, breeding, and wintering waterbirds depending on this region includes grebes, pelicans, cormorants, anhingas, wading birds, waterfowl, coots, rails, gallinules, shorebirds, gulls, terns, and kingfishers. These taxa utilize the artificial freshwater wetland habitat provided by the agricultural wetlands. Numerous other birds utilize riparian areas associated with these artificial wetlands. Crawfish ponds are especially valuable cool season habitat for predaceous waterbirds because they provide shallow water systems rich in invertebrate and small vertebrate prey during the period from mid-autumn through mid-spring when most rice fields are drained. Because most crawfish ponds are not drained until late spring or early summer, predictable, food-rich, shallow water waterbird habitat is available throughout the region when rice fields are being cultivated for rice production. Incorporation of crawfish management into government-sponsored land conservation programs should encourage land owners to sustain standing water habitat outside of program mandated fill/drain requirements. Farmers could adjust the times when their impoundments are filled or drained to maximize benefits to many species, especially migrating shorebirds.

Agricultural wetlands, waterbirds, habitat, crawfish, rice, management.

Khoa, S. N., K. Lorenzen., C. Garaway, B. Chamsinhg, D. Siebert, and M. Randone. 2005.
Impacts of Irrigation on Fisheries in Rain-Fed Rice-Farming Landscapes. *Journal of Applied Ecology*, 42(5), 892-900.

1. Expanding irrigation development threatens the productive and diverse fisheries of rain-fed rice-farming landscapes. Environmental management of irrigation can minimize negative impacts on fisheries, but its effectiveness is constrained by a lack of reliable information on the nature and magnitude of impacts. 2. To quantify the impacts of small- to medium-scale irrigation schemes on aquatic habitat availability, fish catches, species richness and ecological composition of fish assemblages in these landscapes, we conducted a field study in Laos. The observational study was replicated at irrigation scheme level, covering 10 weir and 10 dam irrigation schemes paired with non-impacted control sites. 3. Weir schemes had no significant impact on aquatic habitat, but caused a significant decline (-36%) in fish catches that was only partly explained by a reduction in fishing effort. Weirs had no effect on species richness, but were associated with a significant increase (+17%) in the relative abundance of omnivores. 4. Dam irrigation schemes significantly reduced riverine habitat area, and increased lacustrine and dry-season rice-field areas. Dams led to a marked redistribution of catch and fishing effort from non-reservoir habitats into reservoirs, but no overall change in catch or effort occurred. The redistribution reflected a response to fishing opportunities in the reservoir, rather than a loss of productivity in non-reservoir habitats. No significant impacts were detected on fish species richness or the relative abundance of functional feeding groups. 5. Overall impacts of irrigation on fisheries were related mostly to changes in fishing effort, rather than ecological effects on the resources. The unexpectedly moderate level of ecological impacts may reflect compensatory effects at the landscape level and the fact that rice fields, which dominated the wet-season habitat, continued to be managed as rain-fed deep-water systems even where dry-season irrigation had been developed. 6. Synthesis and applications. Small- to medium-scale irrigation schemes in rain-fed rice-farming landscapes have only moderate

impacts on fisheries, which remain productive and diverse. Changes in agricultural practices in the wet season are likely to have greater effects on fisheries than dry-season irrigation.

Kushlan, J. A. 1986. The Management of Wetlands for Aquatic Birds. *Colonial Waterbirds*, 9(2), 246-248.

A primary use of wetlands in North America is their management for hunted waterfowl. Other wetland systems are managed for various purposes, or are not consistently managed at all. Recent studies on wetland use by birds demonstrate forcefully that wetlands of all sorts are valuable habitat, including small and isolated wetlands that are actively managed for other purposes. Even the great wetlands such as the Everglades and Llanos will require increasing amounts of active management to retain their value as avian habitat. The importance of small wetlands is well demonstrated in Europe and needs to be better appreciated in North America. Such wetlands may be crucial for some regional bird populations even if used intermittently. Maintenance of avian populations in wetlands will require research on the responses of bird populations to management and also the institution of active management to achieve specific goals, in which birds should figure prominently.

Leighton, F. A., and G. Wobeser. 1994. Salinity and Selenium Content in Western Canadian Wetlands. *Wildlife Society Bulletin*, 22(1):111-116.

An important area for duck production in North America is the Prairie Pothole Region that includes parts of 5 northern states and the Prairie Provinces of Canada. Over 50% of the original wetlands in the United States have been lost; the same factors are diminishing wetlands in Canada (Environment Canada 1986). The North American Waterfowl Management Plan (NAWMP) is a conservation and management effort by Canada and the United States with waterfowl population and habitat goals to be met by the year 2000; the Prairie Pothole Region has top priority for protection in the NAWMP (Environment Canada 1986). Two factors that may limit the suitability of wetlands in this area are salinity and selenium. Many wetlands are within closed drainage systems formed by glacial action. Because evaporation exceeds precipitation, salts leach from soil and accumulate in the water (Hammer and Haynes 1978). This process may be exacerbated by agricultural practices that result in soil salinization.

Alberta, ducks, Manitoba, salinity, Saskatchewan, selenium, waterfowl, wetlands

Moreno-Mateos, D., C. Pedrocchi, and F. Comín. 2009. Avian communities' preferences in recently created agricultural wetlands in irrigated landscapes of semi-arid areas. *Biodiversity and Conservation*, 18(4):811-828.

Numerous wetlands have been created spontaneously in the Ebro river basin as a consequence of new irrigation developments over the last 50 years. Water used for irrigating farmland drains into the lower parts of small valleys to form wetlands that are mostly dominated by common reed (*Phragmites australis*). Bird communities established in these wetlands are still simple, partly due to the lack of management to enable their ecological functions to improve. A knowledge of which environmental features favor these bird communities is essential in order to improve the design of newly created or restored wetlands associated to future irrigation developments. For this purpose, the habitat and vegetation features of 15 wetlands have been sampled. The structure of bird communities (richness, abundance and diversity) was monitored over 3 years during the breeding

season and in winter at foraging and nocturnal roosting. The presence of bushes, height of stems and distance from large wetlands (>1 ha) proved to be the most influential variables on bird community structure and on most abundant species during the breeding season. Wetland area and compactness influenced species richness and the most abundant species during winter foraging and roosting. There was a maximum stem height at which only reed-dwelling birds remained. Uncontrolled winter burning had a severe negative effect upon these recently established populations. The ecological functions of newly created or restored wetlands, including those for run-off treatment in agricultural catchments, could be substantially improved taking into account simple guidelines from these results which relate bird community characteristics to wetland features.

Waterbirds; Winter birds; Mediterranean; *Phragmites australis*; Winter burning

Peralta, A., and W. Walker. 2004. Bird Use of Habitat Created by Irrigation and Drainage Practices in the Delta, Utah Area *Critical Transitions in Water and Environmental Resources Management*, 1-10.

Irrigation impoundments, canals, drainage ditches, irrigated fields, and the incidental wetlands created by irrigation and drainage, provide valuable habitat for birds in and around Delta, Utah. Documentation of the creation of these areas and observations of bird use from 1995-2004 during migration, breeding, and wintering are reported. 147 species of birds were observed using incidentally created habitat sites.

Remsen, J. V. S., M.M.; S.W. Cardiff; K.V.T Rosenberg. 1991. The importance of the rice growing areas of south-central Louisiana to winter populations of shorebirds, raptors, waders and other birds. *Journal of Louisiana Ornithology*, 1:37-47.

A census was conducted on 21 February 1988 within a 3522 sq. km area in the ricegrowing region of south-central Louisiana by counting birds from roads that transect the area. An extrapolation from the transect counts of four separate parties to the 3086 sq. km of fields within the census area provides estimates of the abundance of certain species. These estimates show that the region supports important populations of several herons (especially Great Egret, Snowy Egret, and Great Blue Heron), two ibises (White and White-faced), three captors (Northern Harrier, Red-tailed Hawk, and American Kestrel), several shorebirds (especially Long-billed Dowitcher, Western Sandpiper, Killdeer, Dunlin, and Common Snipe), and Loggerhead Shrike. Approximately 225,000 shorebirds may winter in the region. The census, in concert with our additional fieldwork in the region, has documented that several species have either increased greatly or were more common than expected: Glossy Ibis, Canada Goose, Ross' Goose, Black-bellied Plover, Black-necked Stilt, Stilt Sandpiper, Laughing Gull, Gull-billed Tern, and Boat-tailed Grackle. Crows are inexplicably scarce in the region, in spite of seemingly suitable habitat.

W. David Smith, G. L. R., R. Shinn. 1994. A Guide to Wetland Habitat Management in the Central Valley. *California Department Fish and Game, California Waterfowl Association*.

Wetland management can best be described as the active manipulation of wetland habitat. Wetlands evolved as dynamic ecosystems, constantly changing due the physical and chemical processes associated with floods, drought, and fire. Today, most of California's rivers have been contained and the majority of the Central Valley's wetlands seldom experience natural seasonal

flooding. Most wetlands are now enclosed by levees and flooded with water from irrigation district conveyance systems, rivers and sloughs, and/or deep wells. Whereas natural wetland hydrology was very dynamic, flooding cycles now used for managed wetlands are often very predictable. It is the task of the modern wetland manager to emulate natural hydrology and re-create a dynamic, productive wetland system. With only 5% of the Central Valley's original wetlands remaining, it is also imperative that the remaining wetlands are managed such that they support the maximum abundance and diversity of wildlife. The Central Valley supports the single largest concentration of wintering waterfowl in North America, thus Central Valley wetland managers have an enormous responsibility to provide optimum habitat conditions for wintering waterfowl. However, wetland management can be conducted in such a manner that shorebirds, wading birds, breeding ducks, and other wetland-dependent wildlife also realize maximum benefits. The management of productive wetland habitat requires dynamic water management, as well as periodic soil and vegetation disturbances. An adequate water conveyance system is essential for meeting water management objectives, thus pumps, delivery ditches, water control structures, and drainage systems must be maintained in functional condition. Discing, mowing, and burning can be used to interrupt the natural evolution of wetland habitat and to stabilize the marsh vegetation at a point which is the most productive of those elements required by waterfowl and other wetland dependent species. The attached wetland habitat management guides were designed to inform landowners of a variety of management practices that can be used to produce a diversity of productive wetland habitats.

Taft, O. W., C. S. Elphick. C.S. 2007a. Waterbirds on Working Lands: Literature review and bibliography development. *National Audubon Society*, 44.

We conducted a systematic review of the scientific literature, focusing on 216 wetland associated species, and documenting their patterns of use of major row crops in North America (rice, corn, winter wheat, spring wheat, sorghum, soybeans, cotton, peanuts, tobacco), the types of resources available to them in each crop, and the ways in which farming practices affect the value of fields.

Our search process found 550 published papers, of which 350 directly involved waterbird use of crop fields in North America. Most studies were conducted in rice, corn, or wheat, and almost half concerned waterfowl. 120 focal species, including 36 “conservation priority” species, occurred in at least one crop. Rice was used by the most species (105), but corn, wheat, sorghum and soybeans were also each used by at least 30 species. Crops were used primarily for foraging, with most use during nonbreeding periods, but some species also use row crops during the breeding season. Compared to other crops, more species forage in rice fields and more species nest in wheat and rice. Overall, rice, corn, wheat and sorghum appear to have many potential benefits for waterbirds. Soybean fields have some benefits, especially when flooded for wintering species, but also raise a number of concerns. Cotton, peanuts and tobacco appear to provide very little, if any, value for bird species that use wetland habitats. Even for well studied crops, there are clear gaps in current knowledge, ranging from broad-scale, multi-species data on patterns of crop use, to studies that explicitly link use of crop fields to demographic factors that influence population sizes and dynamics. Moreover, there is a clear need for the research and literature to track changes in agronomic practices such that available information relates to current farming activities.

Taft, O. W., C. S. Elphick. 2007b. Waterbirds on Working Lands: Chapter 3. Rice. *National Audubon Society*, 44.

Among row crops worldwide, rice (*Oryza sativa*) is undeniably the crop most associated with use by waterbirds. Rice is typically grown where wetlands formerly occurred, on hydric soils of limited suitability for other crop types (Eadie et al. 2007). With about 86% of ricelands worldwide flooded intentionally or naturally for at least part of the year (Chang and Luh 1991), most rice fields function as valuable surrogate seasonal wetland habitat for waterbirds. Since the world's rice landscapes occur where extensive wetlands formerly existed, the geographic distribution of ricelands overlaps directly with a number of regions of historic importance as habitat for wintering or migrating waterbirds (Eadie et al. 2007). Not surprisingly then, the majority of documented use of row crops by waterbirds has been in ricelands. In North America, major rice growing regions are in the Sacramento Valley of California (Coastal California, or BCR 32), along the Gulf Coast of Texas and Louisiana (Gulf Coast Prairie, or BCR 37), and in the Mississippi Alluvial Valley (MAV; BCR 26) of Arkansas, Missouri, Mississippi and Louisiana (Setia et al. 1994, Eadie et al. 2007). In the Mississippi Alluvial Valley, rice is grown both in the lowland valleys of each state, and in the upland prairie of Arkansas. Figure 3-1 summarizes the typical spatial distribution of rice planted in the U.S. portion of North America (USDA 2007). This chapter summarizes the state of current knowledge regarding the occurrence and abundance of waterbird species in rice fields, important ricefield resources for waterbirds, how waterbirds use rice fields, and the impacts of rice production practices and other management activities on waterbirds. Eadie et al. (2007) conducted an extensive review of the value of North American riceland habitats to wildlife, focusing mostly on waterbird species. Much of the information they provide for North America we summarize here.

Trauth, J. B., S.E. Trauth, and R.L. Johnson. 2006. Best Management Practices and Drought Combine to Silence the Illinois Chorus Frog in Arkansas. *Wildlife Society Bulletin*, 34(2), 514-518.

A primary threat to amphibians in North America is the loss of wetland areas used for reproduction, especially small, temporary, and isolated wetlands. The Illinois chorus frog (*Pseudacris streckeri illinoensis*) is particularly vulnerable and exists today in a highly fragmented distribution limited to a few isolated populations in Arkansas, Illinois, and Missouri. Precision land-leveling combined with seasonal drought conditions has resulted in a significant population decline and range contraction for this species in Arkansas. Distributional surveys conducted from 1987 through 2004 indicate a 61% range contraction from a maximum of 59 km² to a current range of approximately 23 km². Additionally, there has been a lack of recruitment the past 2 years for a species that typically possesses a 2-3-year lifespan. Because the Clean Water Act will only protect isolated vernal pools if the continued existence of a threatened or endangered species is jeopardized, the future of this subspecies of chorus frog in Arkansas is both tenuous and problematic. In the absence of immediate protection and habitat modification through the reintroduction of depressions, we argue extirpation of this species in Arkansas may be imminent. The increasing use of precision land-leveling may have implications for other amphibian species worldwide.

Agriculture, chorus frogs, declining populations, drought, endangered species, precision land-leveling, *Pseudacris streckeri illinoensis*, wetlands.

Whiles, M. R., and B.S. Goldowitz. 2001. Hydrologic Influences on Insect Emergence Production from Central Platte River Wetlands. *Ecological Applications*, 11(6):1829-1842.

The physical template of freshwater ecosystems has a pervasive influence on biological communities and processes. To examine the influence of hydrology on wetland insect communities, we quantified insect emergence from five riparian sloughs in the central Platte River valley. Annual hydroperiods of the wetlands ranged from 94 to 365 d/yr, and frequency and magnitude of drying events were inversely proportional to hydroperiod length. Three emergence traps were placed in each wetland from April through November 1997. Most insects collected in traps were identified to genus, and individual dry mass (DM) also was determined. Abundance of emerging insects (24 124 individuals/m²) and emergence production (5.1 g DM· m⁻²· yr⁻¹) were highest from the site with an intermediate hydroperiod of 296 d. Sites with longer and shorter hydroperiods had lower emergence abundance and production. Emergence production from the perennial site, which contained fish year-round, was only 0.26 g DM· m⁻²· yr⁻¹. Diptera generally dominated emergence trap catches. Chironomidae, Culicidae, and Ceratopogonidae were among the dominant contributors to abundance, whereas Sciomyzidae and Muscidae were important contributors to biomass at most sites. Quadratic equations best described relationships between taxa richness and annual hydroperiod ($r^2 = 0.78$, $P < 0.05$) or number of drying events/yr ($r^2 = 0.81$, $P < 0.05$), reflecting a peak in richness at intermediate levels of both. These relationships followed predictions of the intermediate disturbance hypothesis, but specific mechanisms underlying patterns were difficult to discern. Like emergence production, taxa richness was also highest at intermediate hydroperiods. Hence, insect diversity (measured as richness) and emergence production were positively correlated ($r^2 = 0.85$, $P < 0.05$). Results indicate that the hydrology of central Platte River wetlands exerts a strong influence on insect species richness and emergence production, and that intermittent sites harbor the highest insect diversity and produce more emergent insect biomass. However, trends in seasonal emergence patterns and taxonomic shifts across the hydrologic gradient in this study suggest that a landscape containing a mosaic of hydrologically distinct wetlands will maximize aquatic insect diversity and productivity at larger spatial and temporal scales.

White, C. L., and M.B. Main 2005. Waterbird Use of Created Wetlands in Golf-Course Landscapes. *Wildlife Society Bulletin*, 33(2):411-421.

As human pressures continue to alter and degrade natural wetlands, alternative habitats such as created wetlands may become increasingly important to wetland-dependent species. Golf-course ponds and impoundments in Florida often are used both to store water for irrigation and to prevent extensive flooding during the rainy season. These semipermanent water bodies also may provide habitat for waterbirds. To determine the habitat value of constructed golf-course ponds to waterbirds, we quantified the abundance and diversity of waterbirds using 183 ponds on 12 courses in southwest Florida from January through April 2001 and 2002. We also quantified vegetation and hydrological features of ponds to determine their correlation with waterbird site selection. We recorded 10,474 birds representing 42 species during the 2-year period. We categorized species into 6 foraging guilds, which we used for analyses and management recommendations. In general, results from this study indicate that golf-course ponds are capable of attracting many species of waterbirds. However, analysis of site preference resulted in a wide range of pond features selected by each foraging guild. This finding coupled with low densities of birds (<2 birds/ha for most species) suggested that the value of golf-course ponds may be enhanced through vegetation and hydrological modifications designed to appeal to specific guilds.

5) Water Quality

Champagne, P. 2007. Wetlands Natural Processes and Systems for Hazardous Waste Treatment. 189-256.

The ability of natural wetlands to improve water quality through its physical, chemical and biological processes and their interactions has been recognized for many years. The processes and functions occurring within these natural systems have been modified and adapted for many different types of water quality improvement applications. These systems have proven effective in the mitigation of municipal, agricultural and industrial wastewaters, in reducing the nutrient concentrations of solid waste applied to land, in retaining heavy metals resulting from urban stormwater runoff, drainage and mining activities. In addition to improving water quality, wetlands are also able to store and slowly release surface water, rainfall runoff, groundwater and flood waters. Conversely, they can maintain stream flows during dry periods and replenish groundwater sources. Wetlands also provide a valuable aquatic habitat for a diverse species of flora and fauna.

Chow, A., K. Tanji, and S. Gao 2004. Modeling Drainwater Selenium Removal in Wetlands. *Journal of Irrigation and Drainage Engineering*, 130(1), 60-69.

Prediction of selenium mass distribution and Se speciation in wetlands is desired for a comprehensive assessment of the capability of vegetated wetlands to remove Se from agricultural drainage waters prior to impoundment in evaporation basins. A mathematical model was developed to describe Se transformations and transport in Tulare Lake Drainage District's pilot flow-through wetland cells in California having dimensions of 15 m width and 76 m length. In the model, the wetland cell is subdivided into five subcells and each subcell consists of 10 internal compartments and Se can be transferred between the compartments by physical and chemical processes. Physical processes include water movement, plant litter drop, and physical material breakdown. Chemical processes include Se reduction from selenate to selenite, and further reduction to elemental selenium and organic. In the chemical processes, the Se transformation reaction was assumed to obey first-order kinetics and the Arrhenius equation for temperature dependency. A total of 33 ordinary differential equations were written to describe all the processes within and between the internal compartments. A Fortran program with a numeric subroutine using the fourth order Runge–Kutta method followed by the four-step

Adams–Bashforth–Moulton predictor-corrector method was written to solve the equations simultaneously. The daily rate model was successfully calibrated with data from a test plot planted to Smooth cordgrass and validated with data from test plots planted to Rabbitsfoot grass, Saltgrass, and Cattail. This model provided seasonal variations in Se mass distribution and Se speciation in different compartments by considering seasonal changes in water temperature, Se volatilization rate, and evapotranspiration. Sensitivity analyses on physical parameters such as water inflow rate, water depth, or longitudinal length of a wetland showed that decreasing the inflow rate or increasing the water depth or increasing the longitudinal length of a wetland cell can increase the accumulation of Se in compartments of a wetland cell and reduce the total mass of Se in the outflow water. Such information will be useful for developing engineering design criteria for constructed flow-through wetlands.

Selenium; Wetland; Water pollution; Abatement and removal; California.

Comín, F. A., J. A. Romero, O. Hernández, and M. Menéndez. 2001. Restoration of Wetlands from Abandoned Rice Fields for Nutrient Removal, and Biological Community and Landscape Diversity. *Restoration Ecology*, 9(2):201-208.

A number of experimental freshwater wetlands (150 m long \times 75 m wide) with different ages since they were abandoned as rice fields, were used to analyze the prospects of multipurpose wetland restoration for such degraded areas. Nitrogen and phosphorus removal rate of the wetlands were determined monthly during the flooding season to estimate their efficiency as filters to remove nutrients from agricultural sewage. The number of wetland birds was recorded regularly to identify their habitat preferences. Both the temporal dynamics and changes in the spatial pattern of land use cover during the last 20 years were determined from aerial photographs and field analysis. All the wetlands appeared to be very efficient in the removal of nitrogen and phosphorus exported from rice fields. Usually 50–98% of the nitrogen and less than 50% of the soluble phosphorus were removed by the wetlands at any stage of restoration. Wetland birds preferred wetlands with intermediate plant cover for resting and sleeping activities better than rice fields and either very open wetlands or very dense ones with tall vegetation. Apart from the improvement in water quality and the restoration of natural habitats, restoration of wetland belts around lagoons will increase spatial heterogeneity and diversity of the landscape.

Deppe, M., D. M. McKnight., and C. Blodau. 2009. Effects of Short-Term Drying and Irrigation on Electron Flow in Mesocosms of a Northern Bog and an Alpine Fen. *Environmental Science & Technology*, 44(1):80-86.

Methane emissions and element mobility in wetlands are controlled by soil moisture and redox conditions. We manipulated soil moisture by weekly drying and irrigation of mesocosms of peat from a bog and iron and sulfur rich fen. Water table changed more strongly in the decomposed fen peat (211 cm) than in the fibric bog peat (25 cm), where impacts on redox processes were larger due to larger change in air filled porosity. Methanogenesis was partly decoupled from acetogenesis and acetate accumulated up to 5.6 mmol L⁻¹ in the fen peat after sulfate was depleted. Irrigation and drying led to rapid redox-cycles with sulfate, hydrogen sulfide, nitrate, and methane being produced and consumed on the scale of days, contributing substantially to the total electron flow and suggesting short-term resilience of the microbial community to intermittent aeration. Anaerobic CO₂ production was partly balanced by methanogenesis (0.34%), acetate fermentation (0.86%), and sulfate reduction (1.30%) in the bog peat. In the fen peat unknown electron acceptors and aerenchymatic oxygen influx apparently drove respiration. The results suggest that regular rainfall and subsequent drying may lead to local oxidation-reduction cycles that substantially influence electron flow in electron acceptor poor wetlands.

Fennessy, S., and C. Craft 2011. Agricultural conservation practices increase wetland ecosystem services in the Glaciated Interior Plains. *Ecological Applications*, 21(sp1):S49-S64.

The Glaciated Interior Plains historically supported a broad variety of wetland types, but wetland losses, primarily due to agricultural drainage, range from 50% to 90% of presettlement area. Wholesale land use change has created one of the most productive agricultural regions on earth, but wetland conversion has also led to the loss of the ecosystem services they provide, particularly water quality improvement, flood de-synchronization, carbon sequestration, and support of wetland-dependent species (biodiversity). Nearly three-quarters of the Glaciated Interior Plains fall within the Mississippi River drainage basin, where the combination of extensive tile drainage and

fertilizer use has produced watersheds that contribute some of the highest nitrogen yields per acre to the Mississippi River. Wetland conservation practices implemented under Farm Bill conservation programs have established or involved management of nearly 110 000 ha of wetlands, riparian zones, and associated ecosystem services over the period 2000–2007. We estimated the cumulative ability of these conservation practices to retain sediment, nitrogen, and phosphorus in Upper Mississippi River Basin watersheds. Estimated retention amounts to 1.0%, 1.5%, and 0.8% of the total N, sediment, and P, respectively, reaching the Gulf of Mexico each year. If nutrient reduction is estimated based on the quantity of nutrients exported from the Glaciated Interior Plains region only, the numbers increase to 6.8% of N, 4.9% of P, and 11.5% of sediment generated in the region annually. On a watershed basis, the correlation between the area of wetland conservation practices implemented and per-hectare nutrient yield was 0.81, suggesting that, for water quality improvement, conservation practices are successfully targeting watersheds that are among the most degraded.

The provision of other ecosystem services such as C sequestration and biodiversity is less well studied. At best, implementation of wetland and riparian conservation practices in agricultural landscapes results in improved environmental quality and human health, and strengthens the rationale for expanding conservation practices and programs on agricultural lands.

Carbon sequestration; flood abatement; Glaciated Interior Plains, USA; nitrogen; U.S. Midwest; water quality improvement.

Golterman, H. L. 1995. The labyrinth of nutrient cycles and buffers in wetlands: results based on research in the Camargue (southern France). *Hydrobiologia*, 315(1):39-58.

Wetlands, especially in the Mediterranean area, are subject to severe eutrophication. This may upset the equilibrium between phytoplankton production in undesirable quantities and a quantitatively desirable macrophyte production. In order to manage this equilibrium, a quantitative knowledge of nutrient input and fluxes is essential the role of sediments in these processes must be understood. This knowledge can be useful even for agriculture, e.g. rice cultivation, where optimal utilization of fertilizers can lead to an economic benefit. In this article different aspects of nutrient cycles are discussed in view of approaching a sufficiently precise quantification. The nutrient input balance of the Camargue was therefore measured which showed that the input of nutrients with the irrigation water, taken from the river Rhone, roughly equals the quantity of fertilizers added. Phytoplankton growth can be approached reasonably with the Monod model, although there are still many practical problems, such as the influence of the pH on P uptake and the problem of measuring P uptake in the field. The situation is worse for macrophyte growth; quantitative data are scarce and studies have often been carried out with unrealistic nutrient concentrations or without addressing the influence of the sediment. This influence can also include negative factors, such as high concentrations of Fe^{2+} , H_2S or FeS , but cannot yet be quantified. The nitrogen cycle in wetlands is dominated by denitrification. Most wetlands have sediments with high concentrations of organic matter, therefore with a large reducing capacity. Besides this process, we have shown that denitrification can also be controlled by FeS . In the Camargue sediments this denitrification is mediated by bacteria from the sulfur cycle; this appeared to be the major pathway. It was shown that a stoichiometric relation exists between nitrate reduced and sulphate produced. The influence of the temperature was quantified and appeared to be stronger at high organic matter concentrations than at lower ones. Denitrification with FeS means that the bacteria use nitrate also

for their N demands, while this is not necessarily the case during denitrification with organic matter. Mineralization of macrophytes is a much slower process than that of phytoplankton, probably because of their high C/N ratio. We could, however, not confirm the general assumption that the addition of nitrogen stimulates this mineralization. On the contrary, we found that two amino acids both with a C/N ratio of 6 had different mineralization rates. The amino acid composition of dead macrophytes and the C/N ratio may be of equal importance. Unlike nitrogen, phosphate is always strongly adsorbed onto sediments. The two mechanisms of the adsorption of inorganic phosphate onto sediments, i.e. the adsorption onto Fe(OOH) and the precipitation of apatite, have been quantified. The adsorption of phosphate onto Fe(OOH) can be satisfactorily described with the Freundlich adsorption isotherm: $P_{ads} = A \cdot (o-P)^B$. The adsorption coefficient A depends on the pH of the system and the Ca²⁺ concentration of the overlying water and can be quantified preliminarily by $A = a \cdot 10^{(-0.416 \cdot PH)} (2.86 - (1.86 \cdot e^{-Ca^{2+}}))$. B can be approached by 0.333, which means the cube root of the phosphate concentration. The second mechanism is the solubility of apatite. We found a solubility product of 10⁻⁵⁰ for hard waters. The two mechanisms are combined in solubility diagrams which describe equilibrium situations for specific lakes. The conversion of Fe(OOH) to FeS has a strong influence on phosphate adsorption, although the partial reduction of Fe(OH) ~ P by H₂S does not release significant quantities of phosphate. Even after complete conversion to FeS only a small part of the bound phosphate was released. Besides the two inorganic phosphate compounds, we established the existence of two organic pools, one soluble after extraction with strong acid (ASOP), the other one with strong alkali. The first pool is probably humic bound phosphate, while the larger part of the second pool was phytate. The ASOP was remineralized during the desiccation of a Camargue marsh; this drying up oxidized FeS, thus improving the phosphate adsorption and decreasing the denitrification capacity. It can, therefore, be an important tool for management. The phytate was strongly adsorbed onto Fe(OOH), which explains the non-bioavailability towards bacteria. The fact that the sediment phosphate concentration can be approached by multiplying the relevant sediment adsorption constant with 1/Y_{0_P} concentration has the consequence that much larger quantities of phosphate accumulate in the sediments than in the overlying water. This means that even if the phosphate input is stopped, the eutrophication will only be reversed very slowly, and not at all, if the shallow waters in wetlands have no through flow - as is often the case in many marshes in Mediterranean wetlands.

Knox, A. K., R.A. Dahlgren, K.W. Tate, and E. R. Atwill. 2008. Efficacy of Natural Wetlands to Retain Nutrient, Sediment and Microbial Pollutants All rights reserved. *J. Environ. Qual.*, 37(5):1837-1846.

Wetlands can improve water quality through natural processes including sedimentation, nutrient transformations, and microbial and plant uptake. Tailwater from irrigated pastures may contribute to nonpoint source water pollution in the form of sediments, nutrients, and pathogens that degrade downstream water quality. We examined benefits to water quality provided by a natural, flow-through wetland and a degraded, channelized wetland situated within the flood-irrigation agricultural landscape of the Sierra Nevada foothills of Northern California. The non-degraded, reference wetland significantly improved water quality by reducing loads of total suspended sediments, nitrate, and *Escherichia coli* on average by 77, 60, and 68%, respectively. Retention of total N, total P, and soluble reactive P (SRP) was between 35 and 42% of loads entering the reference wetland. Retention of pollutant loads by the channelized wetland was significantly lower than by the reference wetland for all pollutants except SRP. A net export of sediment and nitrate was observed from the channelized wetland. Decreased irrigation inflow

rates significantly improved retention efficiencies for nitrate, E. coli, and sediments in the reference wetland. We suggest that maintenance of these natural wetlands and regulation of inflow rates can be important aspects of a best management plan to improve water quality as water runs off of irrigated pastures.

Leighton, F. A., and G. Webeser 1994. Salinity and Selenium Content in Western Canadian Wetlands. *Wildlife Society Bulletin*, 22(1):111-116.

An important area for duck production in North America is the Prairie Pothole Region that includes parts of 5 northern states and the Prairie Provinces of Canada. Over 50% of the original wetlands in the United States have been lost; the same factors are diminishing wetlands in Canada (Environment Canada 1986). The North American Waterfowl Management Plan (NAWMP) is a conservation and management effort by Canada and the United States with waterfowl population and habitat goals to be met by the year 2000; the Prairie Pothole Region has top priority for protection in the NAWMP (Environment Canada 1986). Two factors that may limit the suitability of wetlands in this area are salinity and selenium. Many wetlands are within closed drainage systems formed by glacial action. Because evaporation exceeds precipitation, salts leach from soil and accumulate in the water (Hammer and Haynes 1978). This process may be exacerbated by agricultural practices that result in soil salinization.

Alberta, ducks, Manitoba, salinity, Saskatchewan, selenium, waterfowl, wetlands

Lemly, A. D. 1994. Irrigated agriculture and freshwater wetlands: A struggle for coexistence in the western United States. *Wetlands Ecology and Management*, 3(1):3-15.

This paper is a review of the major environmental problems associated with irrigated agriculture in the western United States. Freshwater wetlands are being contaminated by subsurface agricultural irrigation drainage in many locations. Historic freshwater inflows have been diverted for agricultural use, and remaining freshwater supplies are not sufficient to maintain these important natural areas once they are degraded by irrigation drainage. Migratory birds have been poisoned by drainwater contaminants on at least six national wildlife refuges; waterfowl populations are threatened in the Pacific and Central flyways. Revised water allocation policies and regulatory actions are probably necessary to correct existing damage and prevent future problems. The benefits of maintaining healthy wetlands should be used as a rationale for negotiating increases in freshwater supplies. Cost analyses that show the importance of wetlands in dollar values are critical to the success of these negotiations. The next few years will provide unique opportunities for wetland managers to use cost analyses to make changes in water allocation policies. Federally subsidized water has supported and expanded agriculture at the expense of native wetlands for over 100 years in the western United States. This trend must be reversed if these wetlands and their fish and wildlife populations are to survive.

Seiler, R. L. 1997. Methods to Identify Areas Susceptible to Irrigation-Induced Selenium Contamination in the Western United States. *Fact Sheet FS-038-97, U.S. Geological Survey* (Department of the Interior).

Before 1980, regulation of irrigation return flow from agricultural projects focused mainly on management of salts, nutrients, and pesticide residues. In the early 1980's, selenium mobilized by irrigation water was discovered to be the cause of congenital deformities and mortality of birds at

Kesterson Reservoir, a National Wildlife Refuge in central California. This unforeseen result of using irrigation drain water to sustain a wetland prompted the U.S. Department of the Interior (DOI) to create the National Irrigation Water Quality Program (NIWQP) to determine whether events at Kesterson could happen elsewhere in the United States. Satellite imagery indicates that more than 66,000 mi² of land in the 17 conterminous Western States is irrigated for agriculture. Because complete investigation of every irrigated area in the Western United States is impractical, managers need to be able to predict where selenium contamination is likely.

6) Irrigated Wetland Hydrology

De Voogt, K., G. Kite, P. Droogers, and H Murray Rust. (2000). Modelling Water Allocation between a Wetland and Irrigated Agriculture in the Gediz Basin, Turkey. *International Journal of Water Resources Development*, 16(4):639-650.

The Ku y Cenneti is a wetland in the Gediz River Delta in Turkey. Part of it needs a large supply of low saline water to ensure the survival of endangered bird species. Any increase must be supplied at the expense of the upstream irrigated agriculture. The effects of basin water reallocation on water availability and crop productivity were evaluated using a semi-distributed hydrological model (SLURP). It was found that, during the irrigation season, increased wetland water demand causes increased loss in yield to irrigated agriculture and, outside this period, the water supply is limited by the Gediz River minimum base flow.

Fernald, A., S. Cevik., C. Ochoa, V. Tidwell, J. King, and S. Guldán. 2010. River Hydrograph Retransmission Functions of Irrigated Valley Surface Water–Groundwater Interactions. *Journal of Irrigation and Drainage Engineering*, 136(12):823-835.

Storage and release functions of western U.S. traditional river valley irrigation systems may counteract early and rapid spring river runoff associated with climate variation. Along the Rio Grande in northern New Mexico, we instrumented a 20-km-long irrigated valley to measure water balance components from 2005 to 2007. Hydrologic processes of the system were incorporated into a system dynamics model to test scenarios of changed water use. Of river water diverted into an earthen irrigation canal system, some was consumed by crop evapotranspiration _7.4%_, the rest returned to the river as surface return flow _59.3%_ and shallow groundwater return flow that originated as seepage from canals _12.1%_ and fields _21.2%_. The modeled simulations showed that the coupled surface water irrigation system and shallow aquifer act together to store water underground and then release it to the river, effectively retransmitting river flow until later in the year. Water use conversion to nonirrigation purposes and reduced seepage from canals and fields will likely result in higher spring runoff and lower fall and winter river flow.

River-aquifer interaction; Hydrology; Hydrologic models; Hydrogeology; Irrigation systems; Surface water; Groundwater; Groundwater recharge; Rio Grande.

Fernald, A. G., and S.J. Guldán 2006. Surface Water–Groundwater Interactions Between Irrigation Ditches, Alluvial Aquifers, and Streams. *Reviews in Fisheries Science*, 14(1-2):79-89.

Improved descriptions of surface water–groundwater interactions are required for enhanced water resource management in irrigated areas of the western U.S. We are conducting a research project to determine surface water–groundwater interaction effects on hydrologic budgets and water quality

along the upper Rio Grande in New Mexico. This article reports on the initial phase of the project to ascertain the effects of unlined irrigation ditch seepage on shallow groundwater at the Alcalde Science Center in north-central New Mexico. Results from two seepage tests in which 60- and 80 m-long impoundments were established in the Alcalde Ditch indicate that under normal ditch flow depths about 11 cm/day seeps out of the Alcalde Ditch. Based on flow estimates over the 9 km length of the Alcalde Ditch, at least 5% of the total ditch flow seeps out of the ditch bed and banks during the irrigation season. Water level measurements from monitoring wells showed that within 1 month of the beginning of ditch flow, irrigation seepage caused a raised water table and orientation of flow paths towards the river. Specific conductance measurements of surface and shallow groundwater indicated that surface water was the origin of shallow groundwater. Seepage from earthen ditches such as the one in this study could possibly have multiple benefits: diluting agricultural chemicals or septic tank leachate in shallow groundwater, providing groundwater recharge to shallow wells, and providing delayed return flow to the stream thus maintaining in-stream flow after peak runoff periods.

Heermann, D. F. (2003). A Reflection on Irrigation Changes *USDA-ARS-WMU*. Fort Collins, CO.

Irrigation has been practiced for many years perhaps first in Egypt several thousand years ago. There is evidence of irrigation in North America that dates back to the year 500 A D. These systems had evidence of many irrigation ditches moving water from the rivers to the fields in the surrounding valleys. Morgan, 1993 wrote a history of American irrigation titled "Water and the Land." Morgan recognized the irrigation of nearly 200 years ago but wrote that the modern era of irrigation in the United States began in the mid-19th Century as American pioneers moved West. He attributed the teaching of the first college irrigation course in 1883 to Elwood Mead at the Agricultural College of Colorado in Fort Collins. After leaving the college Mead continued his irrigation work for the U.S. Department of Agriculture and as a commissioner of the Bureau of Reclamation. The lake formed by Hoover Dam is named Lake Mead after this agricultural engineer. As a scientist with the Water Management Unit of the USDA in Fort Collins we can trace our roots back to Elwood Mead. The objective of this paper is to review the evolution of modern irrigation technology in the United States and the Central Great Plains. The major focus will be the last century.

Hibbs, B., M. Kelliher, and N. Erdelyi. Use of Environmental Isotopes to Determine Impacts on Wetlands Due to Lining of Irrigation Canals, Salton Sea Area, California *World Environmental and Water Resources Congress 2011*, 1064-1074.

The All American Canal and its Coachella Branch divert water from the Colorado Rivers for use in the Imperial and Coachella Valleys. On the northeast side of the Salton Trough, leakage from the unlined Coachella Canal recharged local aquifers. Wetlands have expanded due to spring discharge below the canal. Wetlands were natural features prior to canal construction, but their areal extent has increased substantially due to leakage from Coachella Canal. Lining of the entire canal was completed in early 2007. Before and after the canal was lined, we collected samples from several spring and well locations down gradient from Coachella Canal to assess geochemical and isotopic signatures for comparison to canal and native groundwater sources. Analysis of stable isotopes of oxygen and hydrogen identifies three distinct groups of water. One group consists of nearly pure canal water, a second group consists of nearly pure native groundwater, and a third group consists of various mixtures of canal and native groundwater. Most of the waters at the preserve are derived from Colorado River-fed canal water. Tritium and Carbon-14 support these interpretations, while

simultaneously providing age-dates of local groundwater. Now that lining of the canal has been completed, flow at the wetlands will decrease. As flow decreases the isotopic and hydrochemical signature of the waters could evolve toward that of native groundwater; this evolution will be a direct result of decreased recharge from the Coachella Canal. A wetland mitigation project has been developed using artificial recharge to maintain adequate flow at the springs, but artificial recharge will amount to no more than 15 to 20% of the canal leakage that occurred before the canal was lined. Continued monitoring of these locations are being done to determine the effects of lining on the current wetland areas.

Harvey, F. E., and S. S. Sibray 2001. Delineating ground water recharge from leaking irrigation canals using water chemistry and isotopes. *Ground Water*, 39(3):408-421.

Across the Great Plains irrigation canals are used to transport water to cropland. Many of these canals are unlined, and leakage from them has been the focus of an ongoing legal, economic, and philosophical debate as to whether this lost water should be considered waste or be viewed as a beneficial and reasonable use since it contributes to regional ground water recharge. While historically there has been much speculation about the impact of canal leakage on local ground water, actual data are scarce. This study was launched to investigate the impact of leakage from the Interstate Canal, in the western panhandle of Nebraska, on the hydrology and water quality of the local aquifer using water chemistry and environmental isotopes. Numerous monitoring wells were installed in and around a small wetland area adjacent to the canal, and ground water levels were monitored from June 1992 until January 1995. Using the water level data, the seepage loss from the canal was estimated. In addition, the canal, the monitoring wells, and several nearby stock and irrigation wells were sampled for inorganic and environmental isotope analysis to assess water quality changes, and to determine the extent of recharge resulting from canal leakage. The results of water level monitoring within study wells indicates a rise in local ground water levels occurs seasonally as a result of leakage during periods when the canal is filled. This rise redirects local ground water flow and provides water to nearby wetland ecosystems during the summer months. Chemical and isotopic results were used to delineate canal, surface, and ground water and indicate that leaking canal water recharges both the surface alluvial aquifer and upper portions of the underlying Brule Aquifer. The results of this study indicate that lining the Interstate Canal could lower ground water levels adjacent to the canal, and could adversely impact the local aquifer.

Kendy, E., and J. D. Bredehoeft. 2006. Transient effects of groundwater pumping and surface-water-irrigation returns on streamflow. *Water Resources Research*, 42(8), W08415.

[1] In surface-water-irrigated western valleys, groundwater discharge from excess irrigation sustains winter streamflow at levels that exceed natural flows. This unnatural condition has persisted for so long that hydrologists, water managers, and water users consider it to be normal. Changing land uses and irrigation practices complicate efforts to manage groundwater discharge and, in turn, to protect instream flows. We examined the impacts on streamflow of (1) seasonal groundwater pumping at various distances from the Gallatin River and (2) improving irrigation efficiency in the Gallatin Valley, Montana. We show that the greater the distance from a seasonally pumping well to a stream, the less the stream depletion fluctuates seasonally and the greater the proportion of annual depletion occurs during the nonirrigation season. Furthermore, we show that increasing irrigation efficiency has implications beyond simply reducing diversions. Improving irrigation efficiency reduces fall and winter flows to a lower, but more natural condition than the artificially high conditions to which we have become accustomed.

However, existing water users and aquatic ecosystems may rely upon return flows from inefficient irrigation systems. By strategically timing and locating artificial recharge within a basin, groundwater and surface water may be managed conjunctively to help maintain desirable streamflow conditions as land uses and irrigation practices change.

Kendy, E., Y. Zhang, C. Liu, J. Wang, and T. Steenhuis. 2004. Groundwater recharge from irrigated cropland in the North China Plain: case study of Luancheng County, Hebei Province, 1949–2000. *Hydrological Processes*, 18(12):2289-2302.

Effective management of limited water resources in the North China Plain requires reliable calculation of historical groundwater balances at local, sub-watershed scales. These calculations typically are hindered by poorly constrained recharge estimates. Using a simple soil-water balance model, we independently calculated annual recharge from irrigated cropland to unconfined alluvial aquifers underlying Luancheng County, Hebei Province, in the western part of the North China Plain, for 1949–2000. Model inputs include basic soil characteristics and daily precipitation, potential evapotranspiration, irrigation, crop root depth, and leaf-area index; model outputs include daily actual evapotranspiration and areal groundwater recharge. Results indicate that areal recharge is not a constant fraction of precipitation plus irrigation, as previously assumed, but rather the fraction increases as the water inputs increase. Thus, model-calculated recharge rates range from 5 to 109 cm year⁻¹, depending on the quantity of precipitation and irrigation applied. The important implication is that, because this drainage recharges the underlying aquifer, improving irrigation efficiency by reducing seepage does not save water. This explains why successful efforts to reduce groundwater pumping for irrigation have had no effect on water-table declines. So long as crop cover is extensive and all crop-water requirements are met—which has been the case in Luancheng County since the 1960s—groundwater levels will continue to decline at a steady rate. Potential solutions include reducing the irrigated area, reintroducing fallow periods, and shifting water from agriculture to other, less consumptive uses.

Lemly, A. D. 1994. Irrigated agriculture and freshwater wetlands: A struggle for coexistence in the western United States. *Wetlands Ecology and Management*, 3(1): 3-15.

This paper is a review of the major environmental problems associated with irrigated agriculture in the western United States. Freshwater wetlands are being contaminated by subsurface agricultural irrigation drainage in many locations. Historic freshwater inflows have been diverted for agricultural use, and remaining freshwater supplies are not sufficient to maintain these important natural areas once they are degraded by irrigation drainage. Migratory birds have been poisoned by drainwater contaminants on at least six national wildlife refuges; waterfowl populations are threatened in the Pacific and Central flyways. Revised water allocation policies and regulatory actions are probably necessary to correct existing damage and prevent future problems. The benefits of maintaining healthy wetlands should be used as a rationale for negotiating increases in freshwater supplies. Cost analyses that show the importance of wetlands in dollar values are critical to the success of these negotiations. The next few years will provide unique opportunities for wetland managers to use cost analyses to make changes in water allocation policies. Federally subsidized water has supported and expanded agriculture at the expense of native wetlands for over 100 years in the western United States. This trend must be reversed if these wetlands and their fish and wildlife populations are to survive.

Loáiciga, H.2007. Approach to Control the Depth of Water in Basin Irrigation and Wetland Flooding. *Journal of Irrigation and Drainage Engineering*, 133(5):500-504.

The controlled ponding of water over level terrain in basin irrigation or wetland flooding is described quantitatively as a three-phase process. During the first phase, water is applied at a known rate until ponding emerges at the time of ponding initiation. In the second phase, water continues to be applied at the same rate until a desired ponded depth is attained. In the third phase, water is applied to maintain the desired ponded depth during an arbitrarily long period. The desired ponded depth is maintained by adjusting the water-application rate to equal the infiltration rate plus the evaporation rate. The time of ponding, the ordinary differential equations governing cumulative infiltration during the second and third phases, and the water-application rate during the third phase are derived in this work using an extended Green-and-Ampt formulation of infiltration. Computational examples illustrate the solutions of the derived ODEs and their application in the control of basin irrigation and wetland flooding.

Infiltration; Evaporation; Irrigation; Soil water; Moisture; Wetlands.

Peck, D., and J. Lovvorn. 2001. The importance of flood irrigation in water supply to wetlands in the Laramie Basin, Wyoming, USA. *Wetlands*, 21(3):370-378.

As in many areas of western North America, flood irrigation for hay production has created many wetlands in the Laramie Basin, Wyoming. Since the early 1900s, water from mountain snowmelt has reached wetlands via ditches and as interflow and ground water percolating from flooded fields and unlined ditches.

Such systems are viewed as inefficient for irrigation and other human uses because they reduce the volume and increase the salinity of downstream flows. Increasing irrigation efficiency by lining ditches or installing sprinklers would decrease wetland habitat, but such effects are seldom considered. To assess potential impacts of increased irrigation efficiency, we determined how flood irrigation affects the hydrology and types of wetlands in the Laramie Basin. For 74 wetlands with 80 total inflows, just 14% of inflows were as surface flow from natural stream channels. In contrast, 65% of inflows were directly from irrigation: 30% as surface flow from ditches and 35% as interflow percolating from ditches and irrigated fields. Fifteen percent of inflows were as surface flow from other wetlands, and 6% of inflows were from ground water with unknown recharge source (probably either natural streams or irrigation). In this year of high water availability (1999), wetlands receiving surface water generally were fresh or oligosaline regardless of whether that flow was from natural streams, other wetlands, or ditches (mean \pm 1 SD \pm 3.28 \pm 5.07 mS/cm, median \pm 1.60, range 0.07–22.10). In contrast, wetlands receiving water as interflow percolating from ditches or irrigated fields, or as ground water with unknown recharge source, were more likely to have conductivities of mesosaline or higher (mean \pm 1 SD \pm 22.45 \pm 32.71 mS/cm, median \pm 9.08, range 0.60–112.00). Conductivity of surface water in the 74 wetlands (mS/cm) ranged from fresh (0.07) to hypersaline (112.00), with a mean of 10.89 \pm 22.80 (SD) and median of 2.60; this range of salinity corresponds to substantial variation in wetland community structure. In the Laramie Basin and similar areas, flood irrigation is critical to the existence, hydrology, and community types of most wetlands, and these effects should be considered in plans to increase irrigation efficiency.

Flood irrigation, irrigation efficiency, Laramie Basin, Rocky Mountain wetlands, saline wetlands, wetland hydrology

Peck, D., D. McLeod, J. Hewlett, and J. Lovvorn 2004. Irrigation-Dependent Wetlands Versus Instream Flow Enhancement: Economics of Water Transfers from Agriculture to Wildlife Uses. *Environmental Management*, 34(6):842-855.

Irrigated agriculture throughout western North America faces increasing pressure to transfer water to nonagricultural uses, including instream flows for fish and wildlife management. In an important case, increased instream flows are needed in Nebraska's Platte River for recovery of threatened and endangered fish and wildlife species. Irrigated agriculture in the Laramie Basin of southeast Wyoming is a potential water source for the effort to enhance instream flow. However, flood irrigation of hayfields in the Laramie Basin has created many wetlands, both ephemeral and permanent, over the last century. Attempting to increase Platte River instream flows by purchasing water rights or improving irrigation efficiency in the Laramie Basin would transform irrigated agriculture, causing a substantial fraction of the Laramie Basin's wetlands to be lost. A creative solution is needed to prevent the sacrifice of one ecosystem on behalf of another. A rotating short-term water-leasing program is proposed. The program allows Laramie Basin producers to contribute to instream flows while continuing to support local wetlands. Permanent wetland desiccation is prevented and regional environmental water needs are met without impairing local ecological resources. Budget analysis is used to provide an initial cost estimate for acquiring water from agriculture through the short-term leasing program. The proposed approach is more expensive than traditional programs but allows contribution to instream flows without major wetland loss. Short-term leasing is a more efficient approach if benefits from wetlands exceed the difference in cost between the short-term lease program and programs that do not conserve wetlands.

Smith, M. B. 2012. Quantifying the relationship between irrigation activities and wetlands in a northern Colorado watershed: assessing this added value of irrigation. MS thesis, Colorado State University.

The construction over the past 130 years of an extensive canal system throughout Colorado has allowed for the spread of irrigated agriculture further and further from the water source. Irrigation activities and associated return flows serve multiple benefits to the surrounding ecosystem health and function, specifically the creation and maintenance of wetlands that would otherwise not exist. This research aims to quantify the relationship between cropland irrigation and down gradient "incidental" wetlands, to allow for the valuation of ecosystem services provided by water in agriculture. Non-linear and multiple-linear regression analyses were used in combination to explain the variability in the size of "incidental" wetlands in a northern Colorado watershed, in response to irrigation application and infrastructure within the contributing areas of each wetland. The explanatory variables included amount of area under flood and sprinkler irrigation, irrigation conveyance structures, and controls for heterogeneities in the landscape, including runoff potential and shallow groundwater flow potential. The analyses were performed using aggregated landscape properties at various distances from the edge of the wetlands, from 50 m to 500 m, in an attempt to identify a spatial area of influence for irrigation activities in the study area. Further analyses included evaluating the impact of changing irrigation scenarios on the size of "incidental" wetlands. The simulated scenarios included increasing application efficiency by converting all flood irrigated lands to sprinkler irrigation; and increasing conveyance efficiency by lining all

existing canals. Research findings include (i) the most significant explanatory variables, irrespective of distance from wetland, were amount of flood-irrigated lands and length of irrigation conveyance structures, (ii) irrigation activities within 200 m of a wetland explained the greatest variability in wetland size ($R^2_{adj} = 0.50$), (iii) increasing runoff potential in the contributing areas, represented by area-weighted curve number values, increased the impact of irrigation variables on the size of "incidental" wetlands, and (iv) increasing irrigation efficiencies in the study area consistently resulted in decreasing total wetland area. Furthermore, an ecosystem benefits transfer model was utilized to estimate the dollar value of the ecosystem services provided by the "incidental" wetlands in the study area. At an estimated value of \$5,647/ha, the ability to evaluate the impact of changing irrigation practices on nearby wetlands may influence the decision process of both landowners and water planners.

Strange, E. M., K.D. Faush, and A.P. Covich. 1999. Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. *Environmental Management*, 24(1):39-54.

Sustaining ecosystem services important to humans while providing a dependable water supply for agriculture and urban needs is a major challenge faced by managers of human-dominated watersheds. Modification of natural flow regimes alters the abundance and composition of native plant and animal communities, affecting ecosystem services such as water storage and nutrient cycling that depend on particular species or functional groups. Because complete restoration of natural hydrology is generally not an option in human-dominated watersheds, there is a need to determine which specific flow manipulations are necessary to restore species-dependent ecosystem services in particular systems. Here we propose a framework for predicting ecological consequences of flow manipulations that is based on the role of hydrology in linking population, community, and ecosystem processes. We use a case-study approach to examine how interactions among the flow regime and species' functional traits help organize local biotic communities and generate alternate states of ecosystem functioning. Results indicate the importance of integrating hydrology and biology to predict ecological consequences of flow regime manipulations and the need to apply general flow-restoration principles on a case-by-case basis.

Sueltenfuss, J., D. Cooper, R. Knight, and R. Waskom 2013. The Creation and Maintenance of Wetland Ecosystems from Irrigation Canal and Reservoir Seepage in a Semi-Arid Landscape. *Wetlands*, 33(5):799-810.

Irrigation has increased agricultural productivity in the arid American West, and has greatly altered the natural landscape. This study sought to identify the hydrologic processes linking irrigation canals and reservoirs to wetlands. We mapped wetlands within an irrigation company service area in northern Colorado, measured groundwater levels, and used stable oxygen isotopes to identify groundwater sources. We related vegetation composition in study wetlands to environmental variables to identify the types of wetlands supported by leakage from irrigation conveyance and storage structures. Ninety-two percent of wetlands were visually connected to the irrigation infrastructure. Wetland water tables varied with adjacent canal flow, and isotopic data indicated that wetlands within the study area were recharged solely by canal leakage. Wetland vegetation composition was related to both soil salinity and groundwater depth. Salt flats formed in areas with high salinity, marsh communities in areas with low salinity and higher standing water, and meadow communities in areas with low salinity and water tables near the ground surface. Though land conversion and water diversions have led to dramatic reductions in historic wetland area in

some places, it is clear from our study that current agricultural landscapes create wetlands that rely on irrigation water.

Keywords Irrigation; Canal seepage; Wetlands

Vepraskas, M. J., C. B. Craft, and J. Richardson. 2002. *Wetland soils: genesis, hydrology, landscapes, and classification*. CRC Press.

Covering wetlands soils from Florida to Alaska, *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification* provides information on all types of hydric soils. With contributions from soil scientists who have extensive field experience, the book focuses on the soil morphology of the wet soils that cover most wetlands from the subtropics northward. No previous book has been devoted solely to the subject of hydric soils and their landscapes. The book is well organized and divided into three parts. Part I examines the basic concepts, processes, and properties of aspects of hydric soils that pertain to virtually any hydric soil. It provides a general overview and important terms and concepts. Part II covers the soils in specific kinds of wetlands and the different functions they perform. Part III emphasizes special wetlands conditions such as soils composed of sand, organic soils in northern North America, prairie wetlands, wetlands in saline situations, dry climates, and wetlands with modified hydrology. Whether you are an expert in soil science, or just need a crash course, this reference prepares you to work with real wetlands-outdoors. Written for scientists without a background in soil science and comprehensive in scope, *Wetlands Soils: Genesis, Hydrology, Landscapes, and Classification* provides basic and advanced coverage, explaining the fundamentals of hydric soils in terms even a non-soil scientist can understand.

Voldseth, R. A., W.C. Johnson., T. Gilmanov., G.R. Guntenspergen., and B.V. Millett. 2007. Model Estimation of Land-Use Effects on Water Levels of Northern Prairie Wetlands. *Ecological Applications*, 17(2):527-540.

Wetlands of the Prairie Pothole Region exist in a matrix of grassland dominated by intensive pastoral and cultivation agriculture. Recent conservation management has emphasized the conversion of cultivated farmland and degraded pastures to intact grassland to improve upland nesting habitat. The consequences of changes in land-use cover that alter watershed processes have not been evaluated relative to their effect on the water budgets and vegetation dynamics of associated wetlands. We simulated the effect of upland agricultural practices on the water budget and vegetation of a semipermanent prairie wetland by modifying a previously published mathematical model (WETSIM). Watershed cover/land-use practices were categorized as unmanaged grassland (native grass, smooth brome), managed grassland (moderately heavily grazed, prescribed burned), cultivated crops (row crop, small grain), and alfalfa hayland. Model simulations showed that differing rates of evapotranspiration and runoff associated with different upland plant-cover categories in the surrounding catchment produced differences in wetland water budgets and linked ecological dynamics. Wetland water levels were highest and vegetation the most dynamic under the managed-grassland simulations, while water levels were the lowest and vegetation the least dynamic under the unmanaged-grassland simulations. The modeling results suggest that unmanaged grassland, often planted for waterfowl nesting, may produce the least favorable wetland conditions for birds, especially in drier regions of the Prairie Pothole Region. These results stand as hypotheses that urgently need to be verified with empirical data.

Wurster, F. C., D. J. Cooper., and W.E. Sanford. 2003. Stream/aquifer interactions at Great Sand Dunes National Monument, Colorado: influences on interdunal wetland disappearance. *Journal of Hydrology*, 271(1–4):77-100.

Between 1937 and 1995 a complex of more than 100 interdunal wetlands disappeared from Great Sand Dunes National Monument, Colorado. We investigated three hypotheses that could explain wetland disappearance: (1) dune movement during a severe drought in the 1950s buried the wetlands, (2) agriculture related ground water pumping lowered the regional water table, and (3) changes in local hydrologic processes led to wetland loss. We used regional stream flow records, ground water level measurements, natural stable isotope analyses, soil stratigraphy, buried seed banks, and ground water modeling to address these hypotheses. Hydrologic data and stable isotope analyses illustrated the interaction between Sand Creek, a nearby stream, and the unconfined aquifer in the area where wetlands occurred. When the intermittent Sand Creek flows, seepage through its bed creates a large ground water mound under the creek. The seasonal development and dispersion of this mound propagates pressure waves through the aquifer that influence ground water levels up to 2 km from Sand Creek. Our data suggest the primary factors contributing to wetland disappearance were recent climatic fluctuations and incision of the Sand Creek channel. Below average stream flow between 1950 and 1980 reduced the duration of Sand Creek flow across the dune complex, minimizing ground water mound development. Consequently, the water table in the unconfined aquifer dropped ~1.0 m and interdunal wetlands dried up. Twentieth Century incision of Sand Creek's channel reduced ground water mound height ~2.5 m, decreasing seasonal water table fluctuations at interdunal wetlands and contributing to the overall water table decline. Long-term wet and dry cycles affect the water table elevation more than channel incision, leading us to conclude that many interdunal wetlands are ephemeral features. Wetland area is maximized during consecutive years of above average Sand Creek discharge and minimized as the water table drops during dry periods.

7) Irrigated Wetland Vegetation

Mushet, D., N. Euliss, and S. Harris. 1992. Effects of irrigation on seed production and vegetative characteristics of four moist-soil plants on impounded wetlands in California. *Wetlands*, 12(3), 204-207.

We examined the effects of irrigation on 4 moist-soil plants commonly managed for waterfowl in the Sacramento Valley, California. Irrigation resulted in taller and heavier swamp timothy (*Heleochoa schoenoides*), pricklegrass (*Crypsis nihaca*), and sprangletop (*Leptochloa fascicularis*). Barnyardgrass (*Echinochloa crusgalli*) grew taller in irrigated wetlands, but no significant difference in weight was detected. Only sprangletop yielded larger seed masses in response to irrigation. Without irrigation, swamp timothy and pricklegrass assumed a typical prostrate growth form, but with irrigation, they assumed a vertical growth form. Irrigation did not significantly affect plant density. Because of rising water costs, wetland managers should consider wildlife management objectives and plant responses before implementing irrigation practices.

California, grasses, hydrophytes, irrigation, moist-soil management, seed production, wetlands.

Summerford, S. E. 2009. Characterization of soil/vegetation on flood irrigated hayfields in Grand Teton National Park, Wyoming : a predictive evaluation tool for agricultural wetlands. thesis. Montana State University.

The Elk Ranch hayfield in Grand Teton National Park (GTNP) has been historically flood-irrigated since the early 20th Century. The park service is now considering closing irrigation to restore native plant communities and enhance Spread Creek fisheries and will need information on the extent of irrigation-created wetlands and how irrigation cessation would change the vegetative component of the ranch. The main objective of this study was to assess the relation between soil and vegetation characteristics of wetland community types at the ranch and to determine if any of the relationships could be used to differentiate between naturally occurring and irrigation created wetlands. Vegetation data were collected from transects centered on a soil pit at 28 randomly located sample points throughout the hayfield. Twenty-six of the 28 sample plots were classified as wetland based on criteria listed by the US Fish and Wildlife Service. Bray-Curtis dissimilarity and nonmetric multi-dimensional scaling were used to analyze percent foliar cover, wetland index value (WIV), soil texture, percent organic matter, redox contrast and abundance, and depth to groundwater and soil saturation for each of the sampled points. The WIV and redox contrast had the greatest dissimilarity (D2), 0.90, and 0.71 respectively across the hayfield. The other measured characteristics had D2 values ranging from 0.23 to 0.49 and were strongly correlated with the WIV and redox contrast measures. However, inclusion of these measures contributed little to the differences already identified. Categorical organization of WIV and redox measures indicated that naturally occurring wetlands could be differentiated from wetlands created by flood irrigation in former upland vegetation communities. Combining wetland index value and soil redox contrast suggests park managers could identify wetland community types likely to remain or transition following cessation of flood irrigation at the Elk Ranch. Additional testing at other GTNP sites will be necessary to test the broad application of this approach and refine the assessment categories.

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